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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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TRANSACTIONS.

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No. 855.

ON THE THEORY OF CONCRETE.

By GEORGE W. RAFTER, M. Am. Soc. C. E.

PRESENTED JUNE 7TH, 1899.

WITH DISCUSSION.

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Tests were made, at the same time, of the voids in the local sand and in the different stones used as aggregates, and also of the tensile strength of the several cements. The results of these tests may be found in Appendix E of the Annual Report of the State Engineer and Surveyor of New York, for the fiscal year ending September 30th, 1894.

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Cement Company's Champion brand, Cumming's Buffalo Portland and Cumming's Buffalo Natural. The detail of this second set of tests may be found in the Appendix to the Annual Report of the State Engineer and Surveyor of New York, for the fiscal year ending September 30th, 1897, to which reference may be made.

Tables Nos. 1 and 2 embody certain results of the second series of tests made in 1896, which, to a large extent, are not included in the report to the State Engineer, and which have seemed to the author to be of possible interest to the members of the Society. They are, therefore, submitted for comment and criticism.

The following explanations are condensed from the author's report to the State Engineer on these tests.

The leading ideas of the tests made in 1896 were: (1) To determine the strength of concretes fabricated with either dry mortars, plastic mortars or mortars with an excess of water; (2) to determine the effect on concrete of exposure to the weather; and (3) to determine the relative value for use in concrete of the Portland cements manufactured in the State of New York. The various qualities of mortar used are designated by the words "dry," "plastic" and "excess." In the dry blocks the mortar was only a little more moist than damp earth. In the plastic blocks the mortar was of the ordinary consistency used by masons. In the excess blocks the water was so far in excess that the concrete quaked like liver, under moderate ramming.

The serial number of Table No. 1 represents a complete series as designated by the Arabic numeral and the letters "a," "b" and "c" of Table No. 1 of the concrete report.* Thus, by way of illustration, Series 1 of Table No. 1 is a combination of blocks 1, 1a, 1b and 1c of Table No. 1 of the report; Series 2 of Table No. 1 represents blocks 2, 2a, 2b and 2c of Table No. 1 of the report, and so on. The headings of the several columns of Table No. 1 are self-explanatory. The blocks were broken on the large Government testing machine at the Watertown Arsenal.

* On referring to Table No. 1 of the report on concrete in the Annual Report of the State Engineer and Surveyor of New York, for 1897, it will be observed that the blocks were made in series of four. Those designated by the Arabic numeral were placed in water when taken from the molds, and allowed to remain until December 1st, 1896, when they were buried in sand, where they remained until taken out for shipment January 10th and 11th, 1896. Blocks marked with the Arabic numeral and the letter "a" stood in a cool cellar from the time of taking from the molds until shipped. Blocks marked with the Arabic numeral and the letter "b" were placed in open air when taken from the molds, and exposed to the weather until shipped. Blocks marked with the Arabic numeral and the letter "c" were placed in open weather when taken from the molds, covered with burlap and wet with water several times a day until November 1st, 1896, after which time they took the weather as it came, until shipped.

The formulas by which the quantities in columns (14), (17), (18) and (19) have been calculated, are as follows:

FORMULA FOR COLUMN (14).

{Dry cement used in batch of concrete,} : {Mortar used in batch of concrete,} :: {Dry cement used in mortar,} : {Cubic feet of mortar made;}

or, Column (14), : Column (11), : : Column (7), : Column (9).

FORMULA FOR COLUMN (17).

{Number volumes mortar in concrete for one of cement,} : {One volume of cement,} :: {Mortar originally made,} : {Cement used in batch of mortar;}

or, Column (17), : 1, : : Column (9), : Column (7).

FORMULA FOR COLUMN (18).

{Number volumes stone used in concrete for one of cement,} : {One volume of cement,} :: {Stone used in batch of concrete,} : {Dry cement used in batch of concrete;}

or, Column (18), : 1, : : Column (12), : Column (14).

FORMULA FOR COLUMN (19).

{Number volumes concrete made for one volume of cement used,} : {One volume of cement,} :: {Concrete actually made,} : {Cement used in batch of concrete;}

or, Column (19), : 1, : : Column (13), : Column (14).

In reference to column (10) of Table No. 1 the author holds that an erroneous nomenclature has considerably obscured the theory and practice of concrete work, so much so that very few contractors and engineers have other than exceedingly general ideas as to the real theory of what is in effect a very simple matter, there being, indeed, very little necessary except to insure the filling of the voids in the aggregate material with mortar. In the author's opinion, therefore, the proper form of expressing concrete relations is not by parts 1: 2: 5; 1: 3: 7, etc.; but rather to express the volume of mortar as a percentage of the volume of stone, the percentage figure used being large enough to represent a little more than the voids in the stone after thorough ramming. The chief object of this paper, therefore, is to point out: (1) The relation existing between the old nomenclature and the new, as proposed by the author, and, (2) to present a brief *résumé* of the results given in detail in the report to the State Engineer and Surveyor.

In Table No. 2 the series have been arranged for the different proportions of cement experimented upon with reference to the consistency

of the mortar, the proportion of sand and cement and the percentage of mortar actually used in each series. Thus, in the first part of Table No. 2 we find compared the Genesee, Wayland and Champion cements for dry mortars with the proportion of sand to cement 1 to 1 and the mortar 33% of the aggregate. In the second division of Table No. 2 the same cements are compared with reference to plastic mortars, other conditions remaining the same; and in the third division they are compared with reference to excess mortars, other conditions remaining the same, and so on, through this table to the summary.

Column 1 of Table No. 2 gives the serial number, the figures there appearing corresponding not only to Table No. 1 of this paper, but also to Table No. 1 of the report to the State Engineer and Surveyor; columns (3), (17), (18), (19) and (20) of this table are the same as the correspondingly numbered columns of Table No. 1 of this paper. Column A of Table No. 2 gives the percentage of shrinkage due to ramming. Thus, column (18) represents the actual quantity of stone used, and column (19) the actual quantity of concrete obtained from mortar and stone as per columns (17) and (18). In the case of the Genesee, Wayland and Champion brands, 1 to 1 mortar, 33% in the aggregate was tried; this shrinkage is found to be, as a mean, 9.3%; for the same cements in plastic mortar, other conditions the same, the shrinkage is 9.1%, and for excess mortars, 9.2 per cent. Broadly, it may be said, therefore, that for 1 to 1 mortars, using 33% of the aggregate, with thorough ramming, about 9% shrinkage may be expected. In the same way, with 1 to 1 mortars, 40% of the aggregate, about 7% shrinkage may be expected. Similar relations, which may be traced through the entire series of tests, are conveniently summarized in Table No. 3.

It will be noticed in studying Table No. 2, that a few of the results are somewhat irregular. On this point the author can only say that very thorough precautions were taken to have the results reasonably accurate. Probably the irregular results are largely due to occasional variations in the quality of the broken stone used for these tests. There were also some variations in the sand, the weight per cubic foot varying from about 86.5 to 93.5 pounds. So far as the author can see, there is no way of avoiding such variations except by determining the voids in the aggregate material for every series of blocks and by actually drying the sand to a uniform consistency. It may be pointed out, however, that such procedure would defeat the

chief object for which these tests were made, namely, to work out methods of procedure which could be conveniently applied in practice, without unduly adding to the cost of concrete. From this point of view the author considers the tests here discussed as exceedingly satisfactory. They are in the fullest sense practical results which may be carried out on work by anybody who will give the theory of concrete moderate study.

It may be further pointed out that columns (15) to (19) of Table No. 1 furnish ready means of computing the proportionate parts of the ingredients for any given volume of concrete.

Many other details could be given, but inasmuch as the object of this paper is to merely call attention to the real points at issue in concrete fabrication and not to repeat statements already in print in the place cited, all details other than those actually necessary for an understanding of the tables of this paper have been omitted. The results are, therefore, submitted in the hope that they may finally lead to more rational concrete practice.

TABLE No. 1.—Data of Concrete Tests.

(1)	(2)	Mortar. (3)	(4)	(5)	(6)	(7)	(8)	(9)	Concrete. (10)	(11)	(12)	(13)	(14)	Proportional Parts by Volume (as per preceding data). (15)	(16)	(17)	(18)	(19)	(20)
Serial number.	Consistency of mortar.	Brand of cement.	Parts of cement by volume.	Parts of sand by volume.	Water used, in pounds per cubic foot of mortar.	Cement actually used, in cubic feet.	Sand actually used, in cubic feet.	Mortar actually made from water, cement and sand, as per columns (6), (7) and (8).	Stone: Ratio to mortar. Percentage.	Mortar actually used in making the quantities of concrete shown in column (13). Cubic feet.	Stone actually used. Cubic feet.	Concrete actually made from mortar and stone as per columns (11) and (12). Cubic feet.	Dry cement actually used in batch of concrete as per column (13). Cubic feet.	Cement.	Sand.	Mortar.	Stone.	Concrete.	Mean ultimate strength of each series of blocks in pounds per square inch.
1	Dry.	Genesee.	1	2	16.6	1	0.40	0.40	33	1.67	5	6.83	0.70	1	2	2.40	7.14	6.90	852
2	Plastic.	"	1	3	19.2	1	0.60	0.60	33	1.67	5	6.83	0.70	1	3	3.00	10.71	9.80	852
3	Excess.	"	1	4	20.7	1	0.80	0.80	33	1.67	5	6.83	0.51	1	4	3.83	14.28	8.82	610
4	Dry	"	1	2	17.0	1	0.45	0.45	40	2.00	5	7.45	0.43	1	2	2.45	9.80	11.62	416
5	"	"	1	3	18.0	1	0.67	0.67	40	2.00	5	7.67	0.61	1	3	3.25	14.70	9.54	416
6	Excess.	"	1	4	22.9	1	0.83	0.83	40	2.00	5	7.83	0.54	1	4	4.25	19.60	6.17	416
7	Dry.	"	1	2	18.4	1	0.45	0.45	40	2.00	5	7.45	0.71	1	2	2.45	9.80	6.42	963
8	"	"	1	3	17.6	1	0.67	0.67	40	2.00	5	7.67	0.81	1	3	3.25	14.70	6.78	963
9	"	"	1	4	17.0	1	0.83	0.83	40	2.00	5	7.83	0.71	1	4	4.25	19.60	6.78	963
10	"	"	1	5	19.1	1	1.00	1.00	40	2.00	5	8.00	0.58	1	5	5.25	24.50	8.12	623
11	"	"	1	6	17.5	1	1.16	1.16	40	2.00	5	8.16	0.58	1	6	6.25	29.40	8.31	623
12	Plastic.	"	1	3	23.1	1	0.67	0.67	33	1.67	5	7.67	1.06	1	3	3.25	14.70	4.71	1,130
13	"	"	1	4	22.0	1	0.83	0.83	33	1.67	5	7.83	0.58	1	4	4.25	19.60	4.70	1,130
14	"	"	1	5	22.4	1	1.00	1.00	33	1.67	5	8.00	0.58	1	5	5.25	24.50	8.03	965
15	Excess	"	1	2	24.5	1	0.45	0.45	40	2.00	5	7.45	0.54	1	2	2.45	9.80	8.98	965
16	"	"	1	3	24.1	1	0.67	0.67	40	2.00	5	7.67	0.81	1	3	3.25	14.70	12.19	939
17	"	"	1	4	20.0	1	0.83	0.83	40	2.00	5	7.83	0.71	1	4	4.25	19.60	11.78	939
18	Dry.	"	1	2	19.7	1	0.45	0.45	40	2.00	5	7.45	0.54	1	2	2.45	9.80	9.54	664
19	"	"	1	3	19.0	1	0.67	0.67	40	2.00	5	7.67	0.81	1	3	3.25	14.70	14.30	664
20	"	"	1	4	18.0	1	0.83	0.83	40	2.00	5	7.83	0.71	1	4	4.25	19.60	16.40	664
21	"	"	1	5	20.4	1	1.00	1.00	40	2.00	5	8.00	0.58	1	5	5.25	24.50	16.40	427
22	"	"	1	6	21.3	1	1.16	1.16	40	2.00	5	8.16	0.58	1	6	6.25	29.40	16.40	427
23	Plastic.	"	1	3	21.3	1	0.67	0.67	33	1.67	5	7.67	0.90	1	3	3.25	14.70	4.70	906
24	"	"	1	4	21.8	1	0.83	0.83	33	1.67	5	7.83	0.90	1	4	4.25	19.60	4.70	906

TABLE No. 1—(*Concluded*).

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
70	Dry.	Ironclad.	1	4	21,3	$\frac{1}{2}$	2	2.06	40	1.8	4.5	4.17	0.43	1	4	4.12	10.46	9.70	1 652
71	Plastic.	"	1	2	.....	1	2	2.69	40	1.8	4.5	4.17	0.67	1	2	2.69	6.71	6.22	2 994
72	"	"	1	3	.....		2	2.25	40	1.8	4.5	4.17	0.54	1	3	3.38	8.38	7.70	1 839
73	"	"	1	4	.....		2	2.23	40	1.8	4.5	.....	0.40	1	4	4.46	11.25	.....	1 544
74	Excess.	"	1	2	.....	1	2	2.62	40	1.8	4.5	4.17	0.69	1	2	2.62	6.51	6.03	2 866
75	"	"	1	3	.....		2	2.27	40	1.8	4.5	4.17	0.53	1	3	3.40	8.50	7.86	2 083
76	"	"	1	4	.....		2	2.27	40	1.8	4.5	4.17	0.40	1	4	4.54	11.25	10.43	1 508
77	Dry.	Empire.	1	2	20,6	$1\frac{1}{2}$		1.87	33	1.5	4.5	4.08	0.60	1	2	2.49	7.50	6.80	3 265
78	"	"	1	3	20.0	2		2,17	33	1.5	4.5	4.08	0.46	1	3	3.25	9.78	8.62	1 992
79	"	"	1	4	18.4	2		2,13	33	1.5	4.5	4.08	0.35	1	4	4.26	12.85	11.65	1 666
80	Plastic.	"	1	2	.....	$1\frac{1}{2}$		1.79	33	1.5	4.5	4.08	0.62	1	2	2.39	6.71	6.09	2 529
81	"	"	1	3	.....	2		2,29	33	1.5	4.5	4.08	0.44	1	3	3.44	10.23	9.26	2 014
82	"	"	1	4	.....	2		2,19	33	1.5	4.5	4.08	0.34	1	4	4.38	13.24	12.00	1 523
83	Excess.	"	1	2	21.7	$1\frac{1}{2}$		1.97	33	1.5	4.5	4.08	0.60	1	2	2.63	7.50	6.80	2 899
84	"	"	1	3	21.7	2		2,29	33	1.5	4.5	4.08	0.44	1	3	3.44	10.23	9.26	1 898
85	"	"	1	4	22,3	2		2,21	33	1.5	4.5	4.08	0.34	1	4	4.42	13.24	12.00	1 488
86	Dry.	"	1	2	20.0	1		2,52	40	1.8	4.5	4.17	0.71	1	2	2.52	6.33	5.87	3 413
87	"	"	1	3	18.2	2		2.15	40	1.8	4.5	4.17	0.56	1	3	3.23	8.08	7.43	2 376
88	"	"	1	4	18.1	2		2.12	40	1.8	4.5	4.17	0.42	1	4	4.24	10.71	9.91	1 806
89	Plastic.	"	1	2	20,7	1		2,56	40	1.8	4.5	4.17	0.70	1	2	2,56	6.43	5.96	3 101
90	"	"	1	3	20.9	2		2.21	40	1.8	4.5	4.20	0.54	1	3	3.32	8.33	7.75	2 123
91	"	"	1	4	20,5	2		2,13	40	1.8	4.5	4.17	0.42	1	4	4.26	10.71	9.93	1 726
92	Excess.	"	1	2	23.4	1		2,56	40	1.8	4.5	4.17	0.70	1	2	2.56	6.43	5.96	2 729
93	"	"	1	3	23.7	2		2.29	40	1.8	4.5	4.17	0.52	1	3	3.44	8.58	8.00	1 913
94	"	"	1	4	22.9	2		2,17	40	1.8	4.5	.....	0.41	1	4	4.34	10.97	.....	1 472
95	Dry.	Champion.	1	1	19.1	$1\frac{1}{2}$	$1\frac{1}{2}$	2,46	33	1.5	4.5	4.08	0.90	1	1	1.64	5.00	4.53	2 659
96	"	"	1	2	18.8	1	2	2.37	33	1.5	4.5	4.17	0.63	1	2	2.37	7.14	6.61	2 289
97	"	"	1	3	17,3	2	2	2,13	33	1.5	4.5	4.17	0.47	1	3	3,17	9.59	8.90	1 401
98	Plastic.	"	1	1	21,3	$1\frac{1}{2}$	$1\frac{1}{2}$	2.37	33	1.5	4.5	4.08	0.94	1	1	1.58	4.79	4.35	2 503
99	"	"	1	2	20,0	1	2	2,42	33	1.5	4.5	4.08	0.62	1	2	2.42	7.25	6.58	2 146
100	"	"	1	3	20.0	2	2	2,17	33	1.5	4.5	4.08	0.46	1	3	3.26	9.78	8.87	1 337
101	Excess.	"	1	1	22,2	$1\frac{1}{2}$	$1\frac{1}{2}$	2.13	33	1.5	4.5	4.08	0.88	1	1	1.70	5.11	4.64	2 279
102	"	"	1	2	21.4	1	2	2,48	33	1.5	4.5	4.08	0.60	1	2	2.48	7.50	6.80	1 862
103	"	"	1	3	24,2	2	2	2.00	33	1.5	4.5	4.08	0.50	1	3	3.00	9.00	8.16	1 168
104	Dry.	"	1	1	18.5	$1\frac{1}{2}$	$1\frac{1}{2}$	1.96	40	1.8	4.5	4.25	1.15	1	1	1.57	3.90	3.70	3 125
105	"	"	1	2	19.4	1	2	2.06	40	1.8	4.5	4.25	0.87	1	2	2.06	5.18	4.90	2 204
106	"	"	1	3	19.0	2	2	2.13	40	1.8	4.5	4.17	0.56	1	3	3.20	8.03	7.44	1 400
107	Plastic.	"	1	1	22,1	$1\frac{1}{2}$	$1\frac{1}{2}$	2.08	40	1.8	4.5	4.08	1.08	1	1	1.66	4.16	3.77	2 608
108	"	"	1	2	.....	1	2	2.44	40	1.8	4.5	4.17	0.74	1	2	2.44	6.08	5.62	2 037
109	"	"	1	3	20,0	2	2	2,19	40	1.8	4.5	4.17	0.55	1	3	3.29	8.18	7.58	1 193
110	Excess.	"	1	1	22,3	$1\frac{1}{2}$	$1\frac{1}{2}$	2,10	40	1.8	4.5	4.17	1.07	1	1	1.68	4.20	4.00	2 196
111	"	"	1	2	21,0	1	2	2,48	40	1.8	4.5	4.17	0.73	1	2	2.48	6.18	5.71	1 711
112	"	"	1	3	22,2	2	2	2.29	40	1.8	4.5	.....	0.52	1	3	3.44	8.65	.....	1 127
113	Plastic.	Buffalo Por'd	1	2	19,6	1	2	2,54	40	1.8	4.5	4.17	0.70	1	2	2.54	6.43	5.96	1 717
114	"	"	1	3	20,0	2	2	2,19	40	1.8	4.5	4.17	0,55	1	3	3.29	8.18	7.58	968

TABLE No. 1—(*Continued*).

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
25	Excess.	Genesee.	1	1	24.0	1¼	1¼	2.50	40	1.8	4.5	4.17	1.08	1	1	1.67	4.16	3.85	3 191
26	"	"	1	2	22.9	1	2	2.75	40	1.8	4.5	4.08	0.66	1	2	2.75	6.82	6.19	2 544
27	"	"	1	3	20.8	¾	2	2.33	40	1.8	4.5	4.08	0.51	1	3	3.50	8.80	8.00	2 107
28	"	"	1	4	21.0	½	2	2.08	40	1.8	4.5	.....	0.43	1	4	4.16	10.40	.....	1 846
29	Dry.	Wayland.	1	1	.....	1¼	1¼	1.87	33	1.5	4.5	4.08	1.00	1	1	1.50	4.50	4.08	4 267
30	"	"	1	2	.....	½	1½	1.64	33	1.5	4.5	4.17	0.68	1	2	2.19	6.62	6.12	2 888
31	"	"	1	3	18.8	¼	2	2.08	33	1.5	4.5	4.17	0.48	1	3	3.12	9.38	8.69	2 056
32	"	"	1	4	17.7	¾	2	2.12	33	1·5	4.5	4.08	0.35	1	4	4.24	12.86	11.66	1 810
33	"	"	1	5	17.1	½	2½	2.58	33	1.5	4.5	4.17	0.29	1	5	5.16	15.41	14.39	1 537
34	Plastic.	"	1	1	19.0	1	1	2.17	33	1.5	4.5	4.08	0.69	1	1	2.17	6.50	5.90	4 072
35	"	"	1	2	21.3	¾	1½	1.83	33	1.5	4.5	4.12	0.61	1	2	2.44	7.39	6.75	2 777
36	"	"	1	3	20.0	½	2	2.12	33	1.5	4.5	4.08	0.47	1	3	3.18	9.57	8.68	2 207
37	"	"	1	4	21.2	¼	2	2.12	33	1.5	4.5	4.08	0.35	1	4	4.24	12.80	11.34	1 600
38	"	"	1	5	22.0	½	2½	2.50	33	1.5	4.5	4.08	0.30	1	5	5.00	15.00	13.60	1 586
39	Excess.	"	1	1	24.3	1	1	1.75	33	1.5	4.5	4.08	0.86	1	1	1.75	5.23	4.75	3 764
40	"	"	1	2	22.1	1	2	2.04	33	1.5	4.5	4.08	0.73	1	2	2.04	6.23	5.55	2 847
41	"	"	1	3	22.4	¾	2	2.08	33	1.5	4.5	4.08	0.48	1	3	3.12	9.37	8.50	1 723
42	"	"	1	4	22.5	½	2	2.12	33	1.5	4.5	4.08	0.35	1	4	4.24	12.71	11.70	1 767
43	"	"	1	5	23.0	¼	2½	2.54	33	1.5	4.5	4.08	0.30	1	5	5.08	15.20	13.60	1 441
44	Dry.	"	1	1	21.0	1½	1½	2.58	40	1.8	4.5	4.17	1.06	1	1	1.72	4.30	3.93	3 966
45	"	"	1	2	21.6	1	2	2.54	40	1.8	4.5	4.17	0.71	1	2	2.54	6.35	5.87	3 404
46	"	"	1	3	20.8	¾	2	2.17	40	1.8	4.5	4.17	0.55	1	3	3.26	8.18	7.59	2 179
47	"	"	1	4	20.8	½	2	2.12	40	1.8	4.5	4.17	0.42	1	4	4.24	10.71	9.92	1 671
48	"	"	1	5	20.7	¼	2½	2.21	40	1.8	4.5	.....	0.40	1	5	4.42	11.25	.....	1 559
49	Plastic.	"	1	1	22.6	1½	1½	2.50	40	1.8	4.5	4.17	1 08	1	1	1.67	4.12	3.86	4 123
50	"	"	1	2	21.8	1	2	2.54	40	1.8	4.5	4.17	0.70	1	2	2.54	6.43	5.96	2 960
51	"	"	1	3	21.6	¾	2	2.21	40	1.8	4.5	4.17	0.54	1	3	3.32	8.29	7.68	2 027
52	"	"	1	4	21.4	½	2	2.17	40	1.8	4.5	4.17	0.41	1	4	4.34	10.97	10.17	1 750
53	"	"	1	5	.....	¼	2½	2.50	40	1.8	4.5	4.17	0.36	1	5	5.00	12.50	11.56	1 465
54	Excess.	"	1	1	22.9	1½	1½	2.62	40	1.8	4.5	4.17	1.03	1	1	1.75	4.37	4.05	3 256
55	"	"	1	2	22.9	1	2	2.58	40	1.8	4.5	4.17	0.70	1	2	2.58	6.43	5.96	3 108
56	"	"	1	3	22.2	¾	2	2.25	40	1.8	4.5	4.17	0.54	1	3	3.38	8.34	7.75	2 016
57	"	"	1	4	22.0	½	2	2.17	40	1.8	4.5	4.17	0.41	1	4	4.34	10.97	10.17	1 670
58	"	"	1	5	.....	¼	2½	2.62	40	1.8	4.5	.....	0.35	1	5	5.24	12.90	.....	1 400
59	Dry.	Ironclad.	1	2	20.0	1½	1½	1.98	33	1.5	4.5	4.08	0.56	1	2	2.64	8.04	7.28	2 777
60	"	"	1	3	20.8	¾	2	2.17	33	1.5	4.5	4.17	0.46	1	3	3.26	9.78	9.06	1 501
61	"	"	1	4	21.2	½	2	2.12	33	1.5	4.5	4.17	0.35	1	4	4.24	12.85	11.90	1 412
62	Plastic.	"	1	2	22.0	½	1½	1.92	33	1.5	4.5	4.08	0.58	1	2	2.56	7.76	7.04	2 552
63	"	"	1	3	22.7	¼	2	2.21	33	1.5	4.5	4.08	0.45	1	3	3.31	10.00	9.06	1 750
64	"	"	1	4	22.4	¾	2	2.12	33	1.5	4.5	4.08	0.35	1	4	4.24	12.85	11.62	1 434
65	Excess.	"	1	2	24.0	½	1½	1.80	33	1.5	4.5	4.08	0.62	1	2	2.40	7.25	6.58	2 436
66	"	"	1	3	.....	¼	2	2.29	33	1.5	4.5	4.08	0.44	1	3	3.44	10.23	9.26	1 718
67	"	"	1	4	23.7	½	2	2.50	33	1.5	4.5	4.17	0.30	1	4	5.00	15.00	13.90	1 584
68	Dry.	Ironclad.	1	2	20.4	1	2	2.50	40	1.8	4.5	4.17	0.72	1	2	2.50	6.25	5.78	3 217
69	"	"	1	3	21.5	¾	2	2.21	40	1.8	4.5	4.17	0.54	1	3	3.32	8.32	7.73	1 929

TABLE No. 2.—Concrete Blocks with Mortar 33% of the Aggregate, in Comparison with Blocks in which the Mortar was 40% of the Aggregate.

Serial number.	Brand of cement.	Mortar.	Stone.	Concrete.	Percentage of shrinkage.	Mean ultimate strength of each series, in pounds per square inch.
(1)	(3)	(17)	(18)	(19)	(A)	(20)
		Dry 1:1. 33⅓ Mortar.				
7	Genesee	1.58	4.71			4 130
29	Wayland	1.50	4.50	4.08		4 267
95	Champion	1.64	5.00	4.53		2 659
	Means	1.57	4.74	4.30	9.3	
		Plastic 1:1. 33⅓ Mortar.				
12	Genesee	1.75	5.25	4.77		3 505
34	Wayland	2.17	6.50	5.90		4 072
98	Champion	1.58	4.79	4.35		2 593
	Means	1.83	5.51	5.01	9.1	
		Excess 1:1. 33⅓ Mortar.				
16	Genesee	1.66	4.98	4.54		3 622
39	Wayland	1.75	5.23	4.75		3 764
101	Champion	1.70	5.11	4.64		2 279
	Means	1.70	5.11	4.64	9.2	
		Dry 1:1. 40% Mortar.				
44	Wayland	1.72	4.30	3.93		3 966
104	Champion	1.57	3.90	3.70		3 125
	Means		4.10	3.82	6.8	
		Plastic 1:1. 40% Mortar.				
49	Wayland	1.67	4.12	3.86		4 123
107	Champion	1.66	4.16	3.77		2 603
	Means	1.66	4.14	3.82	7.7	
		Excess 1:1. 40% Mortar				
25	Genesee	1.67	4.16	3.85		3 191
54	Wayland	1.75	4.37	4.05		3 256
110	Champion	1.68	4.20	4.00		2 196
	Means	1.70	4.24	3.97	6.4	
		Dry 1:2. 33⅓ Mortar.				
1	Genesee	2.40	7.14	6.90		2 852
30	Wayland	2.19	6.62	6.12		2 888
59	Ironclad	2.64	8.04	7.28		2 777
77	Empire	2.49	7.50	6.80		3 265
96	Champion	2.37	7.14	6.61		2 289
	Means	2.42	7.29	6.74	7.5	

TABLE No. 2—(*Continued*).

(1)	(3)	(17)	(18)	(19)	(A)	(20)
		PLASTIC 1 : 2. 33⅓ MORTAR.				
35.....	Wayland.....	2.44	7.39	6.75	.....	2 777
62.....	Ironclad.....	2.56	7.76	7.04	.....	2 552
80.....	Empire.....	2.39	6.71	6.09	.....	2 529
99.....	Champion.....	2.42	7.25	6.58	.....	2 146
.....	Means.....	2.45	7.28	6.62	9.1	.....
		EXCESS 1 : 2. 33⅓ MORTAR.				
17.....	Genesee.....	2.21	6.62	6.06	.....	2 524
40.....	Wayland.....	2.04	6.23	5.55	.....	2 847
65.....	Ironclad.....	2.40	7.25	6.58	.....	2 436
83.....	Empire.....	2.63	7.50	6.80	.....	2 899
102.....	Champion.....	2.48	7.50	6.80	.....	1 862
.....	Means.....	2.35	7.02	6.36	9.4	.....
		DRY 1 : 2. 40% MORTAR.				
19.....	Genesee.....	2.58	6.43	6.54	.....	2 988
45.....	Wayland.....	2.54	6.35	5.87	.....	3 404
68.....	Ironclad.....	2.50	6.25	5.78	.....	3 217
86.....	Empire.....	2.52	6.33	5.87	.....	3 413
105.....	Champion.....	2.06	5.18	4.90	.....	2 204
.....	Means.....	2.44	6.11	5.79	5.3	.....
		PLASTIC 1 : 2. 40% MORTAR.				
22.....	Genesee.....	2.25	5.62	5.26	.....	2 962
50.....	Wayland.....	2.54	6.43	5.96	.....	2 960
71.....	Ironclad.....	2.69	6.71	6.22	.....	2 994
89.....	Empire.....	2.56	6.43	5.96	.....	3 101
108.....	Champion.....	2.44	6.06	5.62	.....	2 037
113.....	Buffalo Portland..	2.54	6.43	5.96	.....	1 717
.....	Means.....	2.50	6.28	5.83	7.1	.....
		EXCESS 1 : 2. 40% MORTAR.				
26.....	Genesee.....	2.75	6.82	6.19	.....	2 544
55.....	Wayland.....	2.58	6.43	5.96	.....	3 168
74.....	Ironclad.....	2.62	6.51	6.03	.....	2 866
92.....	Empire.....	2.56	6.43	5.96	.....	2 729
111.....	Champion.....	2.48	6.18	5.71	.....	1 711
.....	Means.....	2.60	6.47	5.97	7.1	.....
		DRY 1 : 3. 33⅓ MORTAR.				
8.....	Genesee.....	2.97	8.93	8.63	.....	3 065
31.....	Wayland.....	3.12	9.33	8.69	.....	2 056
60.....	Ironclad.....	3.26	9.78	9.06	.....	1 501
78.....	Empire.....	3.25	9.78	8.62	.....	1 992
97.....	Champion.....	3.17	9.59	8.90	.....	1 401
.....	Means.....	3.15	9.49	8.78	7.5	.....
		PLASTIC 1 : 3. 33⅓ MORTAR.				
13.....	Genesee.....	3.38	10.14	8.70	.....	2 311
36.....	Wayland.....	3.18	9.57	8.62	.....	2 207
63.....	Ironclad.....	3.31	10.00	9.06	.....	1 750
81.....	Empire.....	3.44	10.23	9.27	.....	2 014
100.....	Champion.....	3.26	9.78	8.87	.....	1 337
2.....	Genesee.....	3.25	9.80	8.82	.....	2 616
.....	Means.....	3.30	9.92	8.89	10.4	.....

TABLE No. 2—(*Continued*).

(1)	(3)	(17)	(18)	(19)	(A)	(20)
		EXCESS 1 : 3. 33⅓ MORTAR.				
18	Genesee	3.24	9.78	8.96		2 255
41	Wayland	3.12	9.37	8.50		1 723
66	Ironclad	3.44	10.23	9.26		1 718
84	Empire	3.44	10.23	9.26		1 898
103	Champion	3.00	9.00	8.16		1 168
	Means	3.25	9.72	8.83	9.2	
		DRY 1 : 3. 40% MORTAR.				
20	Genesee	3.00	7.50	7.22		2 213
46	Wayland	3.26	8.18	7.59		2 179
69	Ironclad	3.32	8.32	7.73		1 929
87	Empire	3.23	8.03	7.43		2 376
106	Champion	3.20	8.03	7.44		1 400
5	Genesee	3.25	8.12	6.78		2 423
	Means	3.21	8.03	7.36	8.4	
		PLASTIC 1 : 3. 40% MORTAR				
23	Genesee	3.26	8.03	7.44		2 054
51	Wayland	3.32	8.29	7.68		2 027
72	Ironclad	3.38	8.38	7.70		1 839
90	Empire	3.32	8.33	7.75		2 023
109	Champion	3.29	8.18	7.58		1 193
114	Buffalo Portland	3.29	8.18	7.58		958
	Means	3.31	8.23	7.62	7.3	
		EXCESS 1 : 3. 40% MORTAR.				
27	Genesee	3.50	8.80	8.00		2 107
56	Wayland	3.38	8.34	7.75		2 016
75	Ironclad	3.40	8.50	7.86		2 083
93	Empire	3.44	8.58	8.00		1 913
112	Champion	3.44	8.65			1 127
	Means	3.43	8.57	7.90	7.8	
		DRY 1 : 4. 33⅓ MORTAR.				
9	Genesee	4.00	12.19	11.79		2 059
32	Wayland	4.24	12.86	11.66		1 810
61	Ironclad	4.24	12.85	11.90		1 412
79	Empire	4.26	12.85	11.65		1 666
	Means	4.18	12.69	11.75	7.4	
		PLASTIC 1 : 4. 33⅓ MORTAR.				
14	Genesee	4.28	12.86	11.70		2 036
37	Wayland	4.24	12.80	11.34		1 600
64	Ironclad	4.24	12.85	11.62		1 494
82	Empire	4.38	13.24	12.00		1 523
	Means	4.28	12.94	11.66	9.9	
		EXCESS 1 : 4. 33⅓ MORTAR.				
3	Genesee	3.83	11.62	9.54		2 416
42	Wayland	4.24	12.71	11.70		1 767
67	Ironclad	5.00	15.00	13.90		1 594
85	Empire	4.42	13.24	12.00		1 488
	Means	4.37	13.14	11.78	10.0	

TABLE No. 2.—(*Concluded*).

(1)	(3)	(17)	(18)	(19)	(A)	(20)
		DRY 1 : 4. 40% MORTAR.				
21	Genesee	4.34	10.97	.....	.....	1 972
47	Wayland	4.24	10.71	9.92	.....	1 671
70	Ironclad	4.12	10.46	9.70	.....	1 652
88	Empire	4.24	10.71	9.91	.....	1 806
.....	Means	4.24	10.71	9.84	8.1	.....
		PLASTIC 1 : 4. 40% MORTAR.				
24	Genesee	4.34	10.90	10.16	.....	1 828
52	Wayland	4.34	10.97	10.17	.....	1 750
73	Ironclad	4.46	11.25	.....	.....	1 544
91	Empire	4.26	10.71	9.93	.....	1 726
.....	Means	4.35	10.96	10.09	8.0	.....
		EXCESS 1 : 4. 40% MORTAR.				
6	Genesee	4.25	10.63	8.31	.....	2 132
28	Genesee	4.16	10.40	.....	.....	1 846
57	Wayland	4.34	10.97	10.17	.....	1 670
76	Ironclad	4.54	11.25	10.43	.....	1 508
94	Empire	4.34	10.97	.....	.....	1 472
.....	Means	4.33	10.84	9.64	11.0	.....
		DRY 1 : 5. 33⅓ MORTAR.				
10	Genesee	4.92	14.70	14.20	.....	1 664
33	Wayland	5.16	15.41	14.39	.....	1 537
.....	Means	5.04	15.05	14.29	5.1	.....
		PLASTIC 1 : 5. 33⅓ MORTAR.				
15	Genesee	5.00	15.00	13.73	.....	1 801
38	Wayland	5.00	15.00	13.60	.....	1 586
.....	Means	5.00	15.00	13.66	8.3	.....

TABLE No. 3.

Summary of Concrete Tests in Table No. 2.

	33%				40%			
	Number of blocks.	Col. (17) of Table No. 2.	Col. (18) of Table No. 2.	Col. (19) of Table No. 2.	Per cent. of shrinkage.	Number of blocks.	Col. (17) of Table No. 2.	Col. (18) of Table No. 2.	Col. (19) of Table No. 2.	Per cent. of shrinkage.
1 to 1 Mortar.										
Dry	3	1.57	4.74	4.30	9.3	2	1.64	4.10	3.82	6.8
Plastic	3	1.83	5.51	5.01	9.1	2	1.66	4.14	3.82	7.7
Excess	3	1.70	5.11	4.64	9.2	3	1.70	4.24	3.97	6.4
2 to 1 Mortar.										
Dry	5	2.42	7.29	6.74	7.4	6	2.44	6.12	5.89	3.8
Plastic	4	2.45	7.28	6.62	9.1	6	2.50	6.28	5.83	7.2
Excess	5	2.35	7.02	6.36	9.4	5	2.60	6.47	5.97	7.7
3 to 1 Mortar.										
Dry	5	3.15	9.49	8.78	7.5	6	3.21	8.03	7.36	8.4
Plastic	6	3.30	9.92	8.89	10.4	6	3.31	8.23	7.62	7.4
Excess	5	3.25	9.72	8.83	9.2	5	3.43	8.57	7.90	7.8
4 to 1 Mortar.										
Dry	4	4.18	12.69	11.75	7.4	4	4.24	10.71	9.84	8.1
Plastic	4	4.28	12.94	11.66	9.0	4	4.35	10.96	10.09	7.9
Excess	4	4.37	13.14	11.78	10.4	5	4.33	10.84	9.64	11.1
5 to 1 Mortar.										
Dry	2	5.04	15.05	14.29	5.1	1	4.42	11.25	.....	.....
Plastic	2	5.00	15.00	13.66	9.1	1	5.00	12.50	11.56	7.5
Excess	1	5.08	15.20	13.60	10.5	1	5.24	12.90	.....	.....

DISCUSSION.

C. E. FOWLER, M. Am. Soc. C. E.—This subject has impressed the speaker as being a very important one, for the reason that in figuring on work he has, as a rule, found that engineers and contractors know only approximately the quantities of cement, sand and broken stone to order for a given number of yards of concrete of certain specified proportions. The most convenient way of determining these quantities is to prepare tables from which the amounts required for a yard of concrete of any proportion may be taken, using only such proportions as have the voids in the stone entirely or more than filled. Mr. Fowler.

Many writers on this subject have assumed that every concrete, no matter what the proportions may be, has simply a yard of broken stone, without regard to the fact that there is more or less mortar in different proportions. In making up a table of this sort the speaker used the proportions of mortar given in Baker's "Masonry Construction," but found that this did not agree with actual practice. These tables in "Masonry Construction" were made up from theoretical considerations, and it is understood that they are to be revised in a new edition.

TABLE No. 4.—PORTLAND CEMENT CONCRETE.

No.	Proportions.	Barrels cement.	Cubic Yards sand.	Stone, 0.4 voids.	Stone, 0.5 voids.
1	1-2-3	1.77	0.51	0.87	1.05
2	1-2-3½	1.68	0.49	0.91	1.10
3	1-2-4	1.59	0.47	0.95	1.15
4	1-2-4½	1.48	0.44	1.00	1.20
5	1-2-5	1.39	0.42	1.04	1.26
6	1-2-5½	1.30	0.40	1.08	1.30
7	1-3-4	1.30	0.57	0.83	1.00
8	1-3-4½	1.22	0.54	0.89	1.06
9	1-3-5	1.16	0.52	0.92	1.11
10	1-3-5½	1.09	0.50	0.97	1.16
11	1-3-6	1.04	0.48	1.00	1.20
12	1-4-6	1.00	0.55	0.91	1.09
13	1-4-6½	0.96	0.53	0.94	1.13
14	1-4-7	0.92	0.51	0.97	1.17
15	1-4-7½	0.88	0.49	1.00	1.21
16	1-4-8	0.83	0.47	1.03	1.25

About 34 cu. ft. loose = 1 cu. yd. rammed.
Labor = ½ to 2 cu. yds. per man per day.

Table No. 4 was made up some years ago by comparison with actual cases, and has been found to give very satisfactory results in practice. The column for broken stone with 0.4 voids will represent

Mr. Fowler. closely ordinary broken limestone which chips up more than a harder stone and consequently has less voids; while the column with 0.5 voids represents trap rock, the break in which is more angular. It will be readily seen from the table for Portland cement concrete that certain proportions will not have the voids filled and should not be used. For example, with 1 to 3 mortar and with stone having 0.4 voids all the concrete given will have the voids filled, or more than filled, while with 0.5 voids only the 1-3-4 (No. 7) will have the voids filled. The table is made up on the basis of shrinkage under ramming of about 7 cu. ft., and 3.8 cu. ft. of cement to a barrel.

In a recent paper presented to the Society, one of the members stated that concrete was not a fit material for piers of railway bridges, unless a pedestal block of stone was used on which to rest the masonry plates. The speaker would refer that member to the engineers of half a dozen large western roads, who use concrete for piers, and allow the bed plates to rest directly upon the concrete. Concrete is certainly better than most stone, except granite, and probably 50% better than much of the stone commonly used.

Mr. Tillson. G. W. TILLSON, M. Am. Soc. C. E.—The speaker has had some experience in the last few years in mixing concrete for street work, by hand and by machinery. For such work, the layer of concrete is comparatively thin, only 6 ins. thick, as a rule, and the mixer, if a machine is used, must be moved forward to keep out of the way of the finished work. In Brooklyn, for the last two or three years, almost all the concrete for street pavements has been mixed by machinery such as described by Mr. Gould. The method of procedure, however, is a little different. The sand and cement are first thoroughly mixed dry, in the proper proportions, on one side of the machine. The stone is all delivered on the opposite side and is dumped on a plank platform. Before the stone is used, it is thoroughly wet. A gas pipe, perforated throughout its length and running lengthwise inside the cylinder of the machine, admits the water. Then, when the cement and sand are so mixed as to produce a good mortar, an inspection of the material as it comes from the machine indicates whether or not the stone is in the proper proportion to give a good concrete. Good concrete cannot be obtained without good mortar. The specifications call for a 1: 2: 4 mixture, and, generally, there are two men shoveling in the material on the cement side and four men on the stone side, and the shoveling is continuous, on both sides, until the machine has to be moved. The mixer has a gate at the lower end, attended by a man who dumps the concrete into the wheel-barrows. In that way, with proper care, the result is as good as if the work was done by hand, if not better. In both cases the quality depends entirely upon the work being done properly and systematically. Good concrete can be obtained when mixed either by hand or by machinery. When

mixed by hand, the difficulty is, as has been said, to have the mixing done thoroughly. It is hard work, and in warm weather the laborers will get through with a batch as soon as possible. Mr. Tillson.

In making machine-mixed concrete the difficulty is to supply the ingredients in the proper proportions, so that there shall not be an excess of any single material. The stone and cement should be put in at regular intervals. Their supply will be graded very nicely after the men have worked at it a little while, especially if the foreman understands the work. There is great danger, however, in using a machine, if both the foreman and the men are inexperienced.

The relative costs of the two methods, as nearly as the speaker has been able to estimate roughly, by counting the number of men on gangs working by each, are about 7 cents for the machine-mixed and 10 cents for the hand-mixed concrete per square yard, 6 ins. deep. This will doubtless vary 10%, either way, according to the contractor or the foreman.

The speaker has found the amount of water that should be used to be dependent upon conditions. A dry concrete will give good results in cool weather, and the same mixture, in warm weather, will be of practically no value. When the weather is very hot, and when concrete has to be exposed to the air, as when used as foundation for an asphalt pavement, unless it is mixed quite wet the water dries out so rapidly, for the first inch at least, that there is no chance for the chemical action to set in. The result is, that the concrete is dry, and, in many cases, is readily disintegrated near the surface, when, under other conditions, good results would have been obtained. The speaker believes that it is safer to make a concrete a little wet rather than a little dry, and he had the idea that hand-made concrete was better, in the abstract, than machine-made concrete, but judging from some hand-made work seen recently, he believes it fair to say that the machine-made concrete is just as good as the hand-made, and that its quality, in both cases, depends greatly on the care taken in mixing.

H. F. Dunham, M. Am. Soc. C. E.—The presence of dust in the concrete has been mentioned. In certain parts of the country large quantities of limestone are crushed for use in blast furnaces, and in some establishments the limestone is also crushed for concrete. They have, altogether, a heterogeneous product; some of it is very coarse and is used in mills, some is of fine grades and is used for walks when it can be disposed of for that purpose, some is crushed to pass through a $2\frac{1}{2}$ or 2-in. ring, as the case may be, for regular concrete, and there is also a product, called dust-screenings, which resembles a mixture of half flour and half Indian meal, with some pieces as large as a kernel of corn. Mr. Dunham.

The speaker was desirous to see the effect of treating that dust in

Mr. Dunham. connection with concrete just as one would treat sand. He, therefore, made a mixture in proportions of 1 part cement, 2½ parts dust and 3½ parts broken stone of about the size which would pass through a 2-m. ring. A block of about 9 ins. in each dimension was made, kept for a period of two or three weeks and tested. It was loaded to the limit of 3 tons to the square foot, which was more than it was required to bear in the place where it was to be used, and showed no sign of fracture or disintegration. It seemed to be entirely satisfactory. American cement of ordinary grade was used, and, to appreciate the condition fully, it would be necessary to see the so-called dust. It was material which could not well be shoveled if there was any wind.

In an experiment regarding the voids in crushed limestone, an ordinary metal receptacle was first filled with the large broken stone, 2-in. ballast, and then with water, and it was found that the quantity of water required was substantially the same as that required to fill to overflowing the same vessel after it had been completely filled with this so-called dust; showing that the limestone, whatever its condition —probably it would hold true for any grade between those two— would require substantially the same amount of water to completely saturate it and fill the voids.

Mr. Gould. E. SHERMAN GOULD, M. Am. Soc. C. E.—In regard to the comparative merits and quality of hand-made and machine-made concrete, the speaker thinks the impression is somewhat general that the hand-made concrete is the better, but he does not know how that has been ascertained, whether by actual examination or by thinking that it ought to be the best because it is hand-made. Hand-made work of all kinds is often looked upon as being superior. The speaker has been led to take a different view, and in his own experience, as far as he has been able to judge, without applying any critical test, such as testing the tensile or crushing strength of large blocks, but just from the appearance of the concrete, he has been led to think that the machine-made product was the better; and it is natural that it should be, because the mixing of the ingredients of concrete, being one of the hardest kinds of work that a man can do, is often slighted. The material must be turned over thoroughly; the shovels must go down to the bottom of the heap until they scrape against the boards of the platform, and the mixture must be picked up from the bottom and turned over again and again. On the other hand, when the product is put in a machine and stirred around mechanically there must be a more complete and regular mixing than could otherwise be obtained. No doubt there are several ways of making machine-made concrete. The only machine the speaker has used is one with a metallic shaft running through the box, with fins or fans working in the material; the box being on a slant and the material fed in at one end and out at the other. The comparisons of hand-made and machine-made concrete

were made on work which the speaker was executing, and when, in order to gain time, he supplemented the machine by gangs of men making the concrete by hand in the ordinary way, and using the same proportions as in the machine; the relative merits of the two products were judged in that way. The method of making the machine-made concrete was as follows: The sand and cement were measured out on the platform surrounding the machine and mixed dry, only one batch being mixed at a time. The proportions were 1 of cement, 3 of sand and 6 of broken stone. The stone was crushed in a machine. At first it was screened, but was afterward used just as it came from the crusher, and it was believed that the results were better, or at least as good. A barrel of cement was mixed dry with 3 barrels of sand, and each barrel of stone was thoroughly wet. The stone was emptied out on the platform, and then the stone and mortar were shoveled into the mixer. After a short time the men got accustomed to the rate at which the stone and mortar should go in, so that by the time all the stone was gone, all the mortar was also used up and the bed was cleaned off. The water was fed in and was regulated by a valve managed by a man who stood at the lower end of the machine so that he could see the concrete as it fed out into the iron wagons, by which it was conveyed to the work. After a little while the man who was managing the water valve knew the proper consistency; if the concrete was too wet or too dry, word was sent to him and he regulated the water accordingly. The speaker feels quite sure that no hand-made concrete, using the same proportions, could equal that machine-made product, because of the thorough way in which it was churned up. Mr. Gould.

Another point, with which the speaker agrees fully, is that although in a laboratory experiment the dry mortar or concrete is stronger, yet in practice it is very apt to be weaker, and although too much water is bad, too little is a great deal worse. That has always been an axiom with the speaker, and he has found it was difficult to get the necessary amount of tamping done to bring up the moist surface on the dry concrete, without which it is worthless and ought to be removed. If the concrete is so dry that tamping fails to bring the moisture to the surface—indeed it ought to be almost a water surface rather than mere dampness—the concrete is worthless and should be taken out. By putting in a little more water, however, this is avoided, the work is certainly done more quickly and, on the whole, a better result is obtained. The speaker was brought up in the dry school, and got his first education in concrete making from General Gillmore on work which he was executing for him in the rebuilding of Forts Sumter and Moultrie, in Charleston Harbor. All the work there was done according to General Gillmore's directions, under rules which he had given. It is certain that a very fine concrete was produced,

Mr. Gould. but it was with great labor, and was done by day's work. If anything was at all wrong the concrete was simply taken out and the work started over again, nothing which was at all imperfect being allowed to remain. The speaker, however, gradually came around to a freer use of water, and thinks that it gives, upon the whole, a better result. One reason is that in making successive beds of concrete, if they are being brought up in 4 or 6-in. layers, which is apt to be the case, the last bed tamped makes a better bond with the next bed put on if it is a little more moist. The speaker is quite convinced that a section through a large mass of concrete which has been constructed of very dry 6-in. layers would be very apt to show partings between the successive beds. That may or may not be, but the speaker would rather expect to find it, and, more than that, he would be afraid that the dry bed had immediately taken a set and that the placing of the other bed upon it and the tamping—the influence of tamping, of course, is felt through the entire bed—would have a rather disastrous effect upon the partially set concrete in the bed below; whereas, if it is more moist the set does not take place so rapidly, and there is not the same danger in pounding on a bed of concrete which has just commenced to take a set. In other words, if every possible precaution be taken and the work is done under able and constant inspection, it is probable that a little stronger and better product may be obtained with a very dry mixture; yet, taking contract work as it is done all over the country, there is a better chance to get a good result if everything is kept a little moist.

After concrete has been placed, a very important detail is to keep it constantly wet until it is covered over with whatever material is to come on it. Concrete is largely used for foundations upon which stone work is built, but in the speaker's practice all exposed concrete is kept wet for an indefinite period. He has had concrete watered every day and kept constantly wet for probably two or three weeks after it had set. In using hydraulic cement, which is the only kind ever used now, the great point is to let it always have plenty of water, and, after the concrete is all finished, no matter how much water has been used in making and placing it, it should be kept constantly wet, not by dashing water on it, but by sprinkling. The longer this can be done, the better.

The experiment mentioned by Mr. Conrow was conclusive as regards that particular hand-made and machine-made concrete, but the speaker does not think that the two can be spoken of so generally as that. Good hand-made concrete would be better than bad machine-made concrete and *vice versa*. The only way to settle the matter satisfactorily would be to test the very best of each kind.

The greater adhesion in the washed bricks was probably due to the saturation with water. If two bricks are washed and thoroughly

saturated with water their adhesion is very much greater than that of two dry, unwashed bricks. The speaker would attribute the increased adhesion to the moisture. Mr. Gould.

P. W. HENRY, Assoc. M. Am. Soc. C. E.—About a month ago the speaker saw in New Orleans the work which is being done for the Drainage Commission, of which Major Harrod is Chief Engineer. The machine used in mixing the concrete is the ordinary asphalt mixer. It consists of a chamber in which two shafts provided with teeth revolve in opposite directions and draw the mixture toward the center. The sand, cement and shells are placed in receptacles above, which hold the required amount. The dry materials are dumped directly into the mixer, and are mixed dry until all are practically of one color. The water is then turned on. The speaker thinks that the quantity of water is judged by the eye and not measured, but it could be arranged to admit water by volume. The result is an absolutely perfect mixture, if such a thing is possible; because a great number of analyses of asphalt mixtures with that type of machine have shown an identical grading of the sand throughout all parts of the mixture, and also the same amount of bitumen in the mixture. The results in New Orleans are certainly very satisfactory. Whether this style of mixer would be as suitable for trap rock, for instance, which is very heavy, or even for limestone, is a question upon which the speaker is not able to express an opinion. It certainly works very satisfactorily with the shells. Mr. Henry.

The speaker's experience with dry and wet concrete has been confined entirely to laying concrete for asphalt pavements, and indicates that it is safer to use a moderately wet mixture for that purpose. When concrete is laid during hot weather, it is a very good practice to sprinkle the surface every night until the concrete is thoroughly set, or for, say, eight or ten days.

HERMAN CONROW, Jun. Am. Soc. C. E.—In ten of the tests given by the author for "dry," "plastic" and "excess" concrete, under the same conditions, the speaker finds that the average ratios of strength are as follows: Mr. Conrow.

Dry, 29.1; plastic, 26.6; excess, 25.3.

About three years ago the speaker made some experiments upon concrete with especial reference to its economical mixing and laying. The experiments were made under average conditions of mixing by hand, and the figures here given were obtained with a gang of ten men and a foreman. When laying wet concrete, the gang was divided as follows: One foreman, 9 mixers, 1 rammer. An average day's work was 15 cu. yds. of concrete in place. When laying dry concrete, the gang was divided thus: One foreman, 6 mixers, 4 rammers; and, under the same conditions as above, an average day's work was 8 cu. yds. in place. Taking the foreman's wages at $2 per day, and the men at $1.50 each, the cost of laying 1 cu. yd. under the two conditions was as follows:

Mr. Conrow.

Cost of Laying Wet Concrete per Cubic Yard.		Cost of Laying Dry Concrete per Cubic Yard.	
Cement (1 barrel Portland)	$1.50	Cement (1 barrel Portland)	$1.50
Sand	.50	Sand	.50
Stone	1.00	Stone	1.00
Labor	1.13	Labor	2.12
Total	$4.13	Total	$5.12

The dry concrete thus cost 24% more than the wet. From the averages of the previously mentioned ten tests, given by the author, dry concrete is about 15% stronger than wet. Consequently an engineer would not be justified in using dry concrete except in cases where unusual strength was desired, as in arches.

Only those who have handled concrete under actual conditions can realize the greater ease of mixing and laying it when water is freely used. Especially is this true in hot weather. Dry concrete may be an uncertain material, and if the inspector relaxes his vigilance for a few minutes a weak spot is likely to occur in the masonry. Although dry concrete, by a great amount of ramming, may be made stronger than wet concrete, yet if it is not thoroughly rammed it may possess almost no strength, even when the cement is first class. Wet concrete cannot be weak—provided the cement is good and it is reasonably well mixed.

The speaker also experimented with different methods of mixing concrete. After trying various ways the following proved to be the best. Mix the mortar dry; then wet it and mix until all is of the same consistency and about as wet as can be handled easily with shovels. After the stones have been spread evenly to a depth of about 8 ins. and washed clean, spread the mortar over them and then begin the turning. By using wet mortar it saves at least one turning as the mortar percolates through the stones; and three turnings with wet mortar will incorporate more thoroughly than four turnings with dry mortar.

As to the comparative merits of hand-mixed and machine-mixed concrete, the speaker prefers the former, because in most machines there is given no opportunity of thoroughly washing the stone before it is mixed with mortar. The dust rising continually in the machine settles on the stone prior to contact with the mortar, all to the detriment of the concrete. Only by mixing in the open air with plenty of room can the stone be kept perfectly clean until the mortar is applied. The importance of thoroughly mixing the concrete is only equalled by that of having the stones clean.

There is no material used in engineering which is so variable as concrete, and the remedy for a vast amount of poor concrete is the same as in a majority of cases of poor brickwork and weak masonry—the use of plenty of water during construction.

In tearing out some concrete, the speaker noticed that when the

hand-mixed concrete was broken with a sledge hammer, it would almost always break across the stone, thus showing that the concrete was about as good as it was possible to make it. With the machine-mixed concrete, however, it often happened that the stone did not break, but broke away from the cement and left a cavity, showing, evidently, that there was weakness at that point. It is well known that if the stone is covered with a film of dust, the concrete will not be so strong as if it is perfectly clean. The speaker does not see how it would be possible, in the machine described by Mr. Henry, where all the dry materials are first mixed together and then wet, to get a perfect concrete. If, for instance, two bricks, as they come from the brickyard, are laid with a layer of mortar between them, and two other bricks, first washed perfectly clean, are similarly laid, the difference in tensile strength between the two would be very great. The same principle applies to concrete. If all the ingredients are mixed together dry in a machine, the case is exactly the same; dust-covered stone is used and the resulting concrete is not as strong as concrete made from thoroughly washed stone. Mr. Conrow.

ALLEN HAZEN, Assoc. M. Am. Soc. C. E.—The proposition advanced by the author that the best method of determining the proportions of concrete is, first, to decide upon the ratio of sand to cement in the mortar, and, second, to determine the ratio of mortar to stone, is undoubtedly correct, although the conventional method of statement of the relative volumes of the various ingredients is extremely convenient and will doubtless continue to be used. Mr. Hazen.

The paper treats the subject apparently only from the standpoint of the crushing strength of the concrete produced. In very large masses and in foundations the crushing strength is, perhaps, the most important quality of concrete; but concrete is used for many purposes where other properties than crushing strength are of very great and, in fact, of controlling importance. Thus, in exposed positions, a concrete which will resist the action of frost is of the first importance. In other cases, a water-tight concrete is required, and in still others, it is desirable to have concrete which will completely fill forms and yield smooth surfaces, and is of such consistency as to allow the upper surface to be troweled. For all of these purposes a concrete as free from voids as possible is desirable; and to secure satisfactory results it is necessary to use an amount of mortar somewhat more than sufficient to completely fill the voids in the stone.

The proportions of voids in broken stone, gravel and sand are often very large. They are frequently underestimated by defective methods of measurement. The most obvious, and, perhaps, the most common, method used to determine voids is to place the material in a receptacle of known capacity, and to pour as much water into it as possible, measuring the volume of water used. This procedure invari-

Mr. Hazen. ably gives results which are too low, the amount of error depending upon several conditions. The sand or gravel for examination is rarely perfectly dry. Two or 3% of water by weight do not make a material appear particularly moist; but 2 or 3% of water by weight are equal to from 3 to 5% by volume, and if the voids are measured by displacement the results will be too low by this amount.

Another and oftentimes a more serious source of error arises from the fact that all the air is not displaced by the water. With coarse, clean gravels the air can be displaced almost completely, and the error from this source is not large. With dirty materials the error is much greater, and with sands the air cannot be even approximately displaced in this way.

The most accurate and convenient method of determining the voids, known to the writer, is to determine, first, the specific gravity of the solid particles, and, second, the specific gravity of the material as a whole, including the voids. The percentage of space occupied by the particles is then obtained by dividing the specific gravity of the mass as a whole, including the voids, by the specific gravity of the solid particles, and the voids are represented by the difference between the whole volume and the space occupied by the solid particles.

In case the material used for this purpose is not absolutely free from water, the whole or a part of it must be dried after the experiment to determine the amount of water in it, and a correction applied therefor. It will not do to dry a moist material before taking its specific gravity, as the closeness of packing will be very likely to be different for wet and dry materials.

It is usually a comparatively easy matter to determine the specific gravity of the solid particles, but for large classes of materials the specific gravities are so uniform that the errors introduced by assuming an average value of 2.65 are very slight. The specific gravities of sands and gravels of the glacial drift of the Eastern States and of all silicious sands are very close to this figure, and much of the broken stone used for concrete is of nearly the same density. The proportion of voids is thus a direct function of the weight per cubic foot, after allowance is made for moisture. Loosely placed stone, or sand weighing 83 lbs. per cubic foot, has 50% of voids. When compacted to 45% of voids, the weight is increased to 91 lbs. per cubic foot. In the speaker's experience this represents approximately the condition of ordinary building sand as it is usually measured for concrete, and corresponds closely with the weight of sand mentioned by the author. When further compacted to 40% of voids the weight is 99 lbs. per cubic foot. With 35% of voids the weight is 108 lbs., and with 30% of voids, 116 pounds per cubic foot.

The voids in clean gravels or in broken stone without special packing are seldom less than 40%, although they are less when sand,

small fragments of stone or other fine materials are present in considerable amount in the interstices of the larger material. When ballast for concrete contains such material, the amount of sand in the mixture should be reduced by a corresponding amount, but no reduction should be made in the quantity of cement. That is, the fine material in the ballast should be computed as sand, and as entering into the composition of the mortar and not as a part of the ballast. Mr. Hazen.

The proportions of mixing used by the author, namely, with mortar equal to 33 and 40% of the volume of the broken stone, would seem likely to result in the production of concrete with a large proportion of voids. The speaker has never had occasion to use a broken stone which would yield a concrete entirely free from voids when used with as little as 40% of its volume of mortar, and he would expect with as low as 33% that the voids would be large and conspicuous. That this was the case in the author's experiments is suggested by the fact that the percentage of shrinkage on ramming, given in Table No. 3, is substantially the same for 33% of mortar and for 40% of mortar. If the 33% of mortar had filled the voids there would have been an excess of mortar when 40% was used, and the shrinkage by ramming would have been less. As the shrinkage was as much with 40% of mortar as it was with 33%, it seems almost certain that with the smaller quantity the voids were not entirely filled; and in view of general experience, the speaker would be inclined to question whether even the 40% was adequate to fill all the voids.

There are three possible conditions for the amount of mortar in concrete: First, the mortar may be insufficient to fill the voids between the stones; second, it may just fill them; or, third, there may be an excess of mortar. In the first condition, with the voids not entirely filled with mortar, the stones will come to a direct bearing upon each other, and if there is sufficient mortar to prevent them from slipping upon each other, the crushing strength of the concrete may be as great as if more mortar had been used; and for certain purposes such concrete is entirely satisfactory. If the mortar exactly fills the voids the strength certainly will not be less, and for many purposes the concrete will be more satisfactory. Owing to the impossibility of securing perfect mixing, it is practically necessary to use more than enough mortar to fill the voids, in order to make certain that the voids will be filled at every point; and this is the reason usually given for the use of more mortar than the equivalent of the voids, but it is also possible that for some purposes an excess of mortar in itself is desirable.

The use of a sufficient amount of cement to fill the voids in the sand is probably desirable for some purposes, but it is often less necessary than the filling of the voids in the gravel with mortar. Thus, a mortar composed of one part of Portland cement and three

Mr. Hazen. parts of sand is very strong and durable, and sufficient for many purposes, although it can hardly be considered that this amount of cement will entirely fill the voids in the sand. The remaining voids, however, are so small that the mortar is nearly impervious to water, and concrete made from it takes substantially as smooth a finish as that made from a richer mortar.

It should be remembered also that it is not possible to make a concrete entirely free from voids. This arises from the fact that concrete, to be handled conveniently and satisfactorily, requires to have a certain portion of water in it. Some of this water combines with the cement in the process of setting. In some experiments made by the speaker the proportion of water combining in this way amounts to about 8% of the weight of the cement, or to about 1% of the weight of the concrete. This quantity of water is entirely inadequate to give the concrete the proper consistency for the purpose of placing and ramming. In some experiments made by the speaker the proportion of water in concrete as used in actual work amounted 3 or 4% of the weight of the concrete as placed, in addition to the amount required for combination with the cement. To mix the concrete much dryer than this requires a great deal more ramming, which is apt to be neglected under other than very severe inspection, and it is impossible to get smooth, finished surfaces with concrete which is too dry. The above-mentioned percentage of water amounts to 8 or 10% by volume, exclusive of the water which goes into combination with the cement. After the concrete has set, this water will evaporate in the course of time, if it has an opportunity, and the resulting concrete will have a corresponding volume of voids. With the method of manufacture commonly used it is not easy to see how these voids can be entirely avoided, but it is perfectly practicable to have all the voids of extremely small size and in the mortar, and to have no voids visible to the eye and resulting from an insufficiency of mortar in the ballast. Practically, the best concrete, under ordinary conditions of mixing and ramming, and with gravel or broken stone having a specific gravity of about 2.65, will rarely weigh more than 150 lbs. per cubic foot, which corresponds to 9% of voids. Concrete of this compactness, however, with proper materials and well set, resists very well the action of the weather, and the voids are not usually apparent to the eye, or sufficient to allow water to percolate through them to an important extent.

There is a matter in connection with the proportions of mixing concrete which perhaps gives rise to even more perplexity than those mentioned by the author, namely, the measurement of the volume of the cement. The volume of a barrel of cement may be taken as that of a barrel when full, or as the actual volume of the cement in the barrel after it has been shaken down by transportation to a somewhat smaller volume, or the cement may be turned out and measured in

another receptacle. The speaker considers that the ideal condition is to mix concrete by weight, and, as an approach to this condition, in his own practice he has often made the arbitrary assumption that a barrel of cement weighing 380 lbs. net, occupies a space of 3.8 cu. ft., making the weight of cement 100 lbs. per cubic foot. The weight of the cement is determined or checked, no attention is paid to its actual volume, but for the purpose of computation one cubic foot is assumed for each 100 lbs. of cement. The average weight of broken stone or gravel is also approximately 100 lbs. per cubic foot, and on this basis the volumes also express the weights of these materials. The sand is usually lighter, but after the actual weight per cubic foot is determined, the approximate weight can be determined from the volume. Mr. Hazen.

In computing the amounts of the various materials required to make a cubic yard of concrete the following procedure has been used by the speaker with satisfactory results. The weight of a barrel of cement is taken, and 8% is added for water of combination. To this is added the weight of sand free from water which will be used with a barrel of cement, and the corresponding weight of ballast. An estimate is made of the weight per cubic foot of the finished concrete, which, for compact work, may be taken at 150 lbs. per cubic foot, and for concrete with more ballast in proportion to sand, at a lower figure, which can be determined by experiment or estimated approximately from the appearance of the finished work. The ratio of the sum of the weights of these materials to the assumed or determined weight of a cubic foot of finished concrete will give the number of cubic feet made from a barrel of cement. The quantities of the various materials required to make a cubic yard of concrete can then be readily computed. Thus, in a recent case, concrete was mixed in the proportions of one part of cement, computed as above, three parts of sand weighing 90 lbs. per cubic foot, and five parts of broken stone and gravel weighing 100 lbs. per cubic foot. The concrete when dry weighed about 147 lbs. per cubic foot. The proportions of mixing differed slightly in different parts of the work, but the above proportions are about the average.

The computed weight of concrete made from a barrel of cement was as follows:

One barrel of cement	380 lbs.
Water of combination, 8%	30 "
Sand, 11.4 (3.8 x 3) cu. ft., at 90 lbs., dry	1 026 "
Gravel, 19 (3.8 x 5) cu. ft., at 100 lbs., dry	1 900 "
Total weight of concrete made from 1 barrel of cement	3 336 "

Volume produced, $3\,336 \div 147 = 22.7$ cu. ft.

Cement required for 1 cu. yd., $27 \div 22.7 = 1.19$ barrels.

Mr. Hazén. From the records of the work 15 085 cu. yds. of concrete were made from 18 584 barrels of cement, or 1.23 barrels of cement per cubic yard, no deduction being made for ordinary waste, nor for concrete outside of contract lines.

This concrete contains very few voids visible to the eye, when broken or as exposed where it has been placed against forms. All top surfaces were troweled smooth before setting and the proportions were such as to allow this to be satisfactorily done. The proportion of sand to gravel necessary to secure this result was determined by experiment, and was the lowest which could be satisfactorily used. With the volume of sand equal to half of that of the ballast, there were too many voids exposed when the forms were taken down, and there was difficulty in making the top surfaces smooth by troweling. It was thus necessary to use a volume of sand equal to 60% of the volume of the ballast, but for other purposes a wider mixture would be satisfactory and cheaper.

Mr. Harrod. B. M. HARROD, Past-President, Am. Soc. C. E. (by letter).—This paper is very practical and useful. The tables give exact information concerning the losses in bulk of the several ingredients when made into concrete, with which those who have used that material have been familiar in a general way. Five units of cement give about four units of mortar. This is all absorbed in the voids of the stone, which also loses about 10% of its bulk by the readjustment of its particles under the rammer.

In the writer's note-book there is a very old memorandum, to the following effect:

"The theory of concrete-making is to take a barrel of shells, and pour in as much water as the interstices will admit. Then put in a quantity of mortar equal to the bulk of water admitted. If you make any deviation from this, it will be by increasing the mortar."

The authority for this formula is the late General Joseph G. Totten, Chief of Engineers, U. S. A., Hon. M. Am. Soc. C. E.

Adopting this theory, good results can always be assured, whenever there is any doubt concerning the proportion of voids in the stone, as there often is, by specifying a test, with a tight box, containing about half a cubic yard. When this is filled with loose stone, sufficient water should be poured in to fill the voids. After the stone and the sides of the box are saturated and the water is withdrawn, a second charge of water should be poured in and carefully measured. The mass of mortar used should exceed that of the water by 5 or 10 per cent.

The shells alluded to in General Totten's formula are largely used in New Orleans in the place of broken stone on account of their fitness and cheapness. They cost from $1 to $1.25 per cubic yard, which is about half the cost of good broken stone or clean gravel. They are the shells of a small clam (*gnathodon cuneatus*) about the size of a half

dollar. They are found in banks, washed up along the shores of the brackish bayous and lakes in the vicinity of New Orleans, and also in kitchen middens, in such quantities that they are dredged up free from any impurity except a little sand. They have been largely used for roads for many years, and the end of the supply is not in sight. They make a solid concrete, as the thickness and material of the shell give it ample strength, and its concavity forms a good bond. They require a little more mortar than broken stone, and the mixing must be very thoroughly done. The weight of shell concrete is 137.8 lbs. per cubic foot, which is less than that of concrete made with broken stone. This fact, in some cases, is of importance. Mr. Harrod.

WILLIAM M. HALL, M. Am. Soc. C. E. (by letter).—The writer readily admits that the new nomenclature which Mr. Rafter suggests is very good, but can see no reason why the old nomenclature should obscure from those who are looking for it the true theory of concrete mixtures. Mr. Hall.

Referring to the amount of mortar required for mixing with the aggregate, the author well says, "there being, indeed, very little necessary except to insure the filling of the voids in the aggregate material with mortar." It appears well, also, to emphasize the fact that the same statement is true in reference to filling the voids in the sand with cement; also, in reference to the volume of the voids in ordinary sands and aggregates; and, also, that where the sand, cement and aggregate are accurately proportioned, with reference to voids, unless they are thoroughly mixed, the concrete may be, in places, almost worthless.

In lock and dam construction in Kentucky, the writer found voids in sand and aggregate as follows:

The average voids in sand was 31% of the volume.

The sand was clean and sharp, and the size of grains as follows:

Held by No. 20 sieve, 11 per cent.

Passed " 20 " and held by No. 30, 14 per cent.

" " 30 " " " " 50, 53 "

" " 50 " 22 per cent.

The voids in crushed stone and in gravel and mixtures of the two were as follows:

100%	of crushed	2½-in.	stone;	voids,				48%	of volume.
80%	"	2½ "	"	20%	1½-in.	gravel,	voids	44%	"
70%	"	2½ "	"	30%	1½ "	"	"	41%	"
60%	"	2½ "	"	40%	1½ "	"	"	38½%	"
50%	"	2½ "	"	50%	1½ "	"	"	36%	"
				100%	1½ "	"	"	35%	"

The above results are the averages of a number of tests made from several different barge-loads of material. However, the volume of voids in the various mixtures ran quite uniform. The sand and gravel were very clean Ohio River products, taken from the shoal at the mouth of Green River, Ky. The stone was crushed Green River blue limestone,

Mr. Hall. and in texture and color was much like the Hudson River trap. The stone passed a 2½-in. screen and also a fine one to clean it of dust. The gravel passed a 1½-in. screen and then a fine one to remove the sand.

In sea-coast fortification construction in Massachusetts, during the season of 1898, the writer found the volume of voids in sand and aggregate to be as follows:

The average of voids in sand was $31\frac{2}{10}\%$ of the volume.

The voids in stone and gravel and mixtures of the two were as follows:

100%	of crushed	2½-in.	trap; voids,						50%	of volume.
60%	"	2½	"	"	and 40%	1½-in.	gravel,	voids	38¼%	"
50%	"	2½	"	"	" 50%	1½	"	"	36%	"
					100%	1½	"	"	35%	"

The stone was Hudson River trap with the dust removed. The sand and gravel were taken from Long Island Sound, near Willets Point. The gravel was clean, but the sand contained about 8% of loam.

By the foregoing, the writer wishes to call attention to the saving which may be effected by mixing gravel with stone, as an aggregate, instead of using stone alone. He has failed to find similar records in the literature on the subject; but as the voids in these two stones, and the corresponding mixtures with gravel are so nearly uniform, he thinks that nearly the same results will be found with other hard stones having lines of fracture similar to these.

The comparison which the author makes between the concretes made with dry, plastic and very wet mortars are especially interesting. They would be much more instructive, however, if they had included a series of cubes which had seasoned for three or four years.

The conclusions likely to be drawn from these tests are, that dry concrete, when set and hardened, is stronger than wet. It is well known that this result may be obtained from 1-in. mortar briquettes a few months old, and the reverse result from those several years old. Moreover, in tamping the test pieces, it may be assumed that all kinds of concrete were equally well tamped; whereas, in actual practice, the obtaining of well-tamped work with dry concrete is much more difficult than with plastic or wet concrete. In actual construction, the writer prefers concrete with plastic or slightly wet mortar to that which is dry. After setting has commenced, he believes it is advantageous to apply water to the outside surface, or to the interior of the concrete mass by means of well-holes.

Mr. Baker. IRA O. BAKER, M. Am. Soc. C. E. (by letter).—The author deserves credit for the thorough investigation given the practical problem presented, and the special thanks of the profession for the full and careful presentation of the data, particularly the valuable summaries and comparisons.

The writer is much interested in the effect of the amount of

mortar upon the strength of the concrete. Half of the specimens tested contained mortar equal to 33% of the broken stone, and half an amount equal to 40 per cent. Apparently, the broken stone contained 43.3% of voids before tamping and 37.4% after tamping,* and the mortar was measured without tamping. Therefore, owing to the decrease of the volume of the mortar in ramming the concrete, and to the effect of moisture in increasing the volume of the sand, it is probable that the 40% of mortar was not much, if any, more than equal to the voids in the broken stone, when both were rammed. Under the same assumption, the 33% of mortar was equal to about 80% of the voids in the broken stone after the concrete had been tamped into place. Mr. Baker.

Whether or not the 40% of mortar filled the voids, one would naturally expect that an addition of 25% of mortar would give, at least approximately, 25% additional strength. The results of the experiments appear not to support this conclusion.

In Table No. 5 the results are summarized according to the plasticity of the mortar, from which it appears that concrete containing 40% of mortar is only 4% stronger than that containing 33 per cent. Apparently, the plasticity of the mortar makes no material difference in the result.

TABLE No. 5.

Plasticity of mortar.	Amount of Mortar.		Strength of the 40% concrete in terms of that of the 33%.
	33%	40%	
Dry	2 408	2 532	105%
Plastic	2 259	2 329	103%
Excess	2 133	2 227	104%
Mean	2 267	2 363	104%

Summarizing the results according to the proportions of the mortar gives Table No. 6, from which it appears that the concrete containing 40% of mortar is only 3% stronger than that containing 33 per cent.

TABLE No. 6.

Proportions of the mortar.	Amount of Mortar.		Strength of the 40% concrete in terms of that of the 33%.
	33%	40%	
1 : 2	2 640	2 820	107%
1 : 3	1 893	1 905	102%
1 : 4	1 684	1 689	100%
Mean	2 072	2 138	103%

* Report of the New York State Engineer and Surveyor for the year ending September 30th, 1894.

Mr. Baker. The mean increase in strength, from Tables Nos. 5 and 6, differs; owing partly to omitted decimals and partly because the two tables do not refer to exactly the same experiments. The writer, to save labor, used the summaries in the original paper, and they were prepared for a different purpose.

The most interesting deduction from Table No. 6 is that the strength of the concrete increases with the richness of the mortar; and therefore it is better to increase the proportion of the cement in the mortar than to increase the proportion of mortar in the concrete. This is doubtless due to the greater ease with which the richer mortar will flow into the voids during ramming.

Summarizing the results according to the method of storage gives Table No. 7, from which it appears that the method of storage is unimportant. Figured in this way, the concrete with 40% of mortar is 2% stronger than that with 33% of mortar.

TABLE No. 7.

Method of storage for first four months.	Amount of Mortar.		Strength of the 40% concrete in terms of that of the 33%.
	33%	40%	
Under water	2 424	2 448	101%
In a cool cellar	1 992	2 009	101%
In an open shed	1 932	1 999	104%
Under wet burlap	2 007	2 096	104%
Mean	2 089	2 138	102%

Summarizing the results according to the kind of cement used, Table No. 8 is obtained. It is remarkable that the excess strength

TABLE No. 8.

Brand of Portland cement.	Amount of Mortar.		Strength of the 40% concrete in terms of that of the 33%.
	33%	40%	
Genesee	2 587	2 344	91%
Wayland	2 425	2 441	101%
Iron Clad	2 142	2 295	115%
Empire	1 970	1 955	107%
Champion	2 206	2 244	91%
Mean	2 266	2 256	101%

for the concrete containing 40% of mortar, differs so much for the different cements.

It is hoped that the author will explain why the greater percentage of mortar adds so little to the strength of the concrete, and also why

this increase varies so greatly for the different cements. The writer is unable to get any light on these questions from the published data. The experiments are so extensive, and appear to have been conducted so carefully, that it does not seem reasonable to assume that variations therein are chargeable with the above remarkable results. Mr. Baker.

L. J. Le Conte, M. Am. Soc. C. E. (by letter).—The author's criticism on the present practice of making concrete will be concurred in by every engineer who has given the matter any study. It is a humiliating spectacle to see first-class material, manipulated in an irrational and wasteful manner, developing results which cannot be shown to possess a single redeeming feature. Mr. Le Conte.

The tabular results submitted by the author are full of interesting matter, and bring out prominently one feature of considerable practical importance which is not fully appreciated by engineers. The crushing strength of ordinary cement mortars diminishes very nearly in proportion to the quantity of sand added; whereas the author's tables show conclusively that, in the case of concrete, this general law is materially modified. The same general law of diminution of strength follows until the theoretic mortar, 3 to 1, is reached; but for some reason, in the case of all the lower grades of concrete blocks, made with 4 to 1, 5 to 1 and 6 to 1 mortars, the corresponding diminution in crushing strength is noticeable, but much less in degree than would naturally be expected.

Taken as a class, the writer thinks the lower-grade concretes are very much neglected by engineers. In most cases where concrete is used the unit-strength of the concrete is not called into play at all. Dead weight and the distribution of pressures are all that are required, and the lower-grade concretes fulfil these conditions completely and economically.

It is to be regretted that the author did not state clearly the age of the concrete tested, the footnote leading one to suppose that the blocks were about 12 months old.

As to the relative merits of dry, plastic and excess mortars, the writer thinks there is much more danger to be expected from the lack of water than from an excess.

H. Von Schon, Esq. (by letter).—During the spring and summer of 1898, investigations of concrete were carried on under the writer's direction at Sault Ste. Marie, Mich., for the purpose of establishing the most satisfactory and economic constituents and mixtures of concrete to be used in the substructure of a hydraulic power house. The structure in question, being partly subaqueous, must needs be of masonry, and as the only available native material, Potsdam sandstone, was considered of insufficient homogeneity, concrete was selected. The character of the construction called for materials of great density and strength, and the climatic condition for resistance to low temperature, while the extent of the work, requiring about 50 000 cu. yds. of Mr. Von Schon.

Mr. Von Schon.

concrete, suggested a diligent search for the most economical mixture which would secure the desired result. It was therefore to determine the kind of cement and aggregate, and the ratio of mixtures which, together, would yield the proper material for the purpose in hand, that these tests were entered upon.

The general programme as outlined for these tests was:

First.—To operate practically, that is, to avoid the introduction of refinements which could not be followed in actual construction.

Second.—To establish the characteristics of all materials used, namely, the analysis and normals of the cements; the weight, voids, and fineness of the sand; and the weight, voids, sizes and absorption of materials to be used as aggregates.

Third.—To make two concrete bars from each of the following combinations: Four different kinds of cement, four different materials for aggregates and four different ratios of mixtures.

Fourth.—To test each bar to the breaking point, when 60 days old, by applying a load at the center.

All the manipulations were entrusted to two men who had had the advantage of several years' training in the United States cement testing laboratory at this point, under L. C. Sabin, Assoc. M. Am. Soc. C. E., U. S. Assistant Engineer, and Mr. W. W. Dann, Assistant Engineer, who had direct supervision and kept the records. A building was conveniently arranged with material bins, testing and mixing rooms. Storage for the manufactured bars was provided for outside the building.

TABLE No. 9.—Characteristics of Cements.

		Class *E.*	Class *R.*	Class *F.*	Class *N.*
Analysis.	Silica	23.08	21.70	27.48	23.16
	Alumina	5.69	8.76	.....	6 33
	Iron oxide	5.35	1.27	14.42	1.71
	Lime	62.38	63.55	50.39	36.08
	Magnesia	1.21	2.96	3.18	20.38
	Potash and soda	1.66	1.12	....	5.26
	Carbonic acid, etc	0.60	0.50	4.36	7.07
Weight per cubic foot, in pounds		103.08	98.45	77.70	62.78
Fineness passing No. 100 sieve, per cent.		91.4	90	99.00	.....
" " No. 200 " "		73.05	71	95.00	.....
Initial set		1 h. 35 m.	2 h. 25 m.	1 h. 35 m.	0 h. 30 m.
Hard set		3 h. 10 m.	4 h. 40 m.	2 h. 30 m.	1 h. 00 m.
Tensile strength 1 : 3		Lbs.	Lbs.	Lbs.	Lbs.
7 days		235	243	170	32
28 days		340	322	243	67

Four different kinds of cement, representing the chief raw materials from which American cements are manufactured (calcareous rock, calcareous earth, natural cement rock and furnace slag), and each of them a cement of high standing among its class, were used in these tests. The sand was procured from the bed of St. Mary's River,

TABLE No. 10.—CHARACTERISTICS OF SAND AND AGGREGATES.

	Sand.	Sand-stone.	Boulder stone.	Gravel.	Furnace slag.
Size—					
Passing 1½-in. ring, per cent.	.....	100.00	100.00	100.00	.....
Retained on 1-in. ring, per cent.	.....	100.00	100.00	10.70	.....
" " ¾-in. ring, " "	.....	.....	.....	23.65	1.10
" " No. 4 sieve, per cent.	.....	.....	.....	8.70	2.86
" " " 10 " "	.....	.....	.....	17.14	45.62
" " " 20 " "	4.17	.....	.....	21.76	36.92
" " " 30 " "	12.52	.....	.....	6.49	8.26
" " " 40 " "	44.44	.....	.....	5.96	3.24
Passing " 40 " "	38.87	.....	.....	5.59	2.00
Weight per cubic foot dry, pounds	96.45	79.32	84.00	107.36	126.23
Weight per cubic foot wet, pounds	113.46	82.62	86.70	.....	.....
Voids in per cent. of volume	41.7	45.3	48.7	34.08	43.8

TABLE No. 11.—RELATIVE VOLUMES OF CONSTITUENTS IN ONE CUBIC FOOT OF CONCRETE.

Using Sand Stone for Aggregate.

Materials.	Mixture A.			B.			C.			D.			E.		
	Cubic feet.	Pounds.	Ratio of volume.	Cubic feet.	Pounds.	Ratio of volume.	Cubic feet.	Pounds.	Ratio of volume.	Cubic feet.	Pounds.	Ratio of volume.	Cubic feet.	Pounds.	Ratio of volume.
Cement—															
Class E	0.19	19.5	1.00	0.21	21.5	1.00	0.23	23.7	1.00	0.25	25.9	1.00	0.19	19.5	1.0
" R	0.19	18.6	1.00	0.21	20.6	1.00	0.23	22.6	1.00	0.25	24.7	1.00	0.19	18.6	1.0
" F	0.19	14.7	1.00	0.21	15.9	1.00	0.23	17.8	1.00	0.25	19.5	1.00	0.19	14.7	1.0
" N	0.19	11.9	1.00	0.21	13.1	1.00	0.23	14.3	1.00	0.25	15.7	1.00	0.19	11.9	1.0
Lime	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.06	3.8	0.3
Sand	0.45	43.7	2.4	0.50	48.3	2.4	0.55	53.4	2.4	0.60	58.2	2.4	0.60	58.2	3.1
Water	0.11	7.0	0.6	0.13	8.0	0.6	0.14	9.0	0.6	0.16	10.0	0.6	0.19	12.0	1.0
Sand Stone (S. S.)	1.0	82.6	5.3	1.0	82.6	4.8	1.00	82.6	4.4	1.00	82.6	4.0	1.00	82.6	5.3

Using Boulder Stone for Aggregate.

Cement—															
Class E	0.20	21.0	1.00	0.22	23.0	1.00	0.24	25.3	1.00	0.26	27.4	1.00	0.20	21.0	1.0
" R	0.20	20.0	1.00	0.22	22.0	1.00	0.24	24.1	1.00	0.26	26.1	1.00	0.20	20.0	1.0
" F	0.20	15.7	1.00	0.22	17.4	1.00	0.24	19.0	1.00	0.26	20.6	1.00	0.20	15.7	1.0
" N	0.20	12.7	1.00	0.22	14.0	1.00	0.24	15.4	1.00	0.26	16.7	1.00	0.20	12.7	1.0
Sand	0.49	47.0	2.45	0.54	52.0	2.45	0.59	56.6	2.45	0.64	61.4	2.46	0.64	61.4	3.0
Water	0.13	8.0	0.65	0.14	9.0	0.65	0.15	10.0	0.65	0.16	10.6	0.65	0.20	12.5	1.3
Lime	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.06	3.8	0.2
Boulder Stone (B. S.)	1.0	86.7	5.0	1.0	86.7	4.35	1.0	86.7	4.16	1.0	86.7	3.85	1.0	86.7	5.0

Lime weighs 63.75 lbs. per cubic foot.

Mr. Von Schon.

and is known as Point aux Pins sand. The materials used for aggregates were of the native Potsdam sandstone, granitic boulder stone, gravel and furnace slag (see Tables Nos. 9 and 10).

The ratios used were: For the "*A*" mixture, such proportions as would just fill the voids, and for "*B*," "*C*" and "*D*" mixtures of a respective addition of 5, 10 and 15% of mortar to the "*A*" mixture. A few bars were made of mixture "*E*" having the ratio of "*D*" mixture, but substituting lime for the cement in the excess mortar quantity. Table No. 11 gives the quantities and ratios of materials for each of the above mixtures, yielding theoretically 1 cu. ft. of concrete.

Knock-down forms were constructed of thoroughly seasoned timber lined with tin, the inside dimensions being precisely 6 ins. square and about 24 ins. long. The mixing was done in batches of 1 cu. ft. of concrete, from which two forms were filled. The operations were the customary ones, namely, spreading dry sand on clean platforms, adding the cement, mixing the sand and cement dry, adding water, mixing the mortar, spreading the wet aggregate on a second platform, adding mortar to the aggregate, mixing the concrete, filling the concrete in the form in 6-in. layers and ramming.

The mixing tools used were spades and hoes. Water was used from the city supply at its natural temperature, about 50° Fahr.; the quantity was determined by the condition of the mortar, which was kept just plastic, without any water standing on or running from it. The rammers used for tamping were of oak, weighing about 8 lbs. The weight of all materials used, of the forms before filling and of the excess material after filling, was taken accurately and recorded. All bars were made during April and May, 1898, and broken at an age of 60 days, during June and July, 1898.

After filling the forms, the end of each bar was marked by its serial number, weighed and left undisturbed for from 2 to 8 days, when the form was removed and the bar placed in storage. At the age of 60 days each bar was weighed and then broken. The breaking apparatus consisted of two rigid timber frames 18 ins. apart, and of a scale platform suspended from a steel beam of triangular shape. The bar was adjusted on the frame, the scale beam with knife-edge on the center of the bar, and the platform was loaded with weights, and finally by pouring sand, until the bar broke, when all weights were taken and recorded. The fractures of the broken bars were examined, and those of exceptional appearance were photographed.

Some of the broken bars were kept for a year, during which time they were exposed to the prevailing weather of the summer and winter season, the latter being especially severe and long. They were then re-examined, weighed, placed in water of natural temperature and weighed daily until no additional absorption was observable (see Table No. 13.)

TABLE No. 12.—History of Fabricated Bars and Breaking Tests. Mr. Von Schon.

Fabricating Data.					Test Data.				
No. of bar.	Cement.	Aggregate.	Mixture.	Weight of bar.	Days in		Weight of bar before breaking.	Breaking weight.	Character of break.
					Form.	Air.			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1..	*E*	S. S.	*A*	73.5	2	58	71.0	1422.5	Clean and sharp.
2..	*E*	S. S.	*A*	73.5	2	58	71.0	1380.75	" "
9..	*E*	S. S.	*B*	73.5	5	55	71.5	1798.75	" "
10..	*E*	S. S.	*B*	76.0	5	55	72.0	1671.0	" "
17..	*E*	S. S.	*C*	75.0	3	57	72.25	2302.25	" "
18..	*E*	S. S.	*C*	75.25	3	57	72.5	2179.00	" "
25..	*E*	S. S.	*D*	77.75	5	55	75.25	2634.25	" "
26..	*E*	S. S.	*D*	78.25	5	55	75.75	2567.75	" "
33..	*E*	S. S	*E*	73.25	6	54	69.25	862.00	" "
34..	*E*	S. S	*E*	73.25	6	54	69.75	777.25	" "
3..	*R*	S. S.	*A*	76.25	2	58	72.5	1444.25	" "
4..	*R*	S. S.	*A*	72.25	2	58	69.5	1264.00	" "
11..	*R*	S. S.	*B*	75.5	5	55	73.5	1461.00	" "
12..	*R*	S. S.	*B*	75.0	5	55	73.0	1339.75	" "
19..	*R*	S. S.	*C*	76.75	5	55	74.5	2134.00	" "
20..	*R*	S. S.	*C*	76.5	5	55	74.5	2064.5	" "
27..	*R*	S. S.	*D*	75.5	5	55	72.5	2207.00	" "
28..	*R*	S. S.	*D*	77.75	5	55	75.0	2027.75	" "
35..	*R*	S. S.	*E*	72.5	6	54	69.0	1558.5	" "
36..	*R*	S. S.	*E*	74.5	6	54	71.0	1357.0	" "
5..	*F*	S. S.	*A*	72.25	5	55	69.75	621.75	Rough and crumbly.
6..	*F*	S. S.	*A*	74.5	5	55	71.5	511.5	" "
13..	*F*	S. S.	*B*	75.25	3	57	72.5	903.75	Clean.
14..	*F*	S. S.	*B*	75.00	3	57	72.25	933.5	"
21..	*F*	S. S.	*C*	73.00	5	55	71.00	1153.00	Clean but green.
22..	*F*	S. S.	*C*	76.75	5	55	74.75	1373.00	" "
29..	*F*	S. S.	*D*	77.00	6	54	74.5	962.25	" "
30..	*F*	S. S.	*D*	77.00	6	54	74.5	919.75	" "
37..	*F*	S. S.	*E*	73.25	6	54	71.0	1013.25	" "
38..	*F*	S. S.	*E*	75.25	6	54	73.0	1034.50	" "
7..	*N*	S. S.	*A*	67.0	5	55	Broke in handling		
8..	*N*	S. S.	*A*	69.75	5	55	"	"	
15..	*N*	S. S.	*B*	73.75	8	52	69.0	285.5	Crumbled.
16..	*N*	S. S.	*B*	73.75	8	52	70.25	305.75	"
23..	*N*	S. S.	*C*	73.5	5	55	69.0	284.75	"
24..	*N*	S. S.	*C*	73.5	5	55	69.0	229.50	"
31..	*N*	S. S.	*D*	73.75	6	54	69.0	351.25	"
32..	*N*	S. S.	*D*	74.00	6	54	69.75	281.00	"
39..	*N*	S. S.	*E*	74.00	10	50	69.00	267.00	"
40..	*N*	S. S.	*E*	72.75	10	50	67.5	246.5	"
41..	*E*	B. S.	*A*	79.25	4	56	77.25	2386.00	Clean and sharp.
42..	*E*	B. S.	*A*	79.00	4	56	77.25	2829.75	" "
49..	*E*	B. S.	*B*	77.25	22	38	75.5	2391.5	" "
50..	*E*	B. S.	*B*	80.25	22	38	78.75	2861.00	" "
57..	*E*	B. S.	*C*	80.25	18	42	78.75	2849.25	" "
58..	*E*	B. S.	*C*	80.25	18	42	78.5	3120.75	" "
65..	*E*	B. S.	*D*	81.75	5	55	80.0	3361.75	" "
66..	*E*	B. S.	*D*	79.75	5	55	77.75	3200.5	" "
73..	*E*	B. S.	*E*	78.00	2	58	75.5	2480.0	" "
74..	*E*	B. S.	*E*	78.00	2	58	75.25	2800.75	" "
43..	*R*	B. S.	*A*	79.75	4	56	77.5	3119.00	" "
44..	*R*	B. S.	*A*	79.75	4	56	77.5	2456.00	" "
51..	*R*	B. S.	*B*	81.25	22	38	79.5	3121.75	" "
52..	*R*	B. S.	*B*	79.5	22	38	77.5	3386.75	" "
59..	*R*	B. S.	*C*	80.0	18	42	78.75	2988.00	" "
60..	*R*	B. S.	*C*	80.0	18	42	78.50	3282.50	" "
67..	*R*	B. S.	*D*	80.0	5	55	77.75	3289.50	" "
68..	*R*	B. S.	*D*	80.5	5	55	78.25	3004.25	" "
75..	*R*	B. S.	*E*	78.25	2	58	74.00	2499.25	" "
76..	*R*	B. S.	*E*	79.25	2	58	76.50	2653.00	" "

Mr. Von Schon.

TABLE No. 12.—(*Concluded.*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
45..	*F*	B. S.	*A*	80.00	4	56	77.5	1183.25	Clean but green.
46..	*F*	B. S.	*A*	73.00	4	56	70.75	901.00	" "
53..	*F*	B. S.	*B*	81.00	18	42	79.25	1266.75	" "
54..	*F*	B. S.	*B*	79.75	18	42	78.00	1490.25	" "
61..	*F*	B S.	*C*	80.25	6	54	78.5	1163.75	" "
62..	*F*	B. S.	*C*	78.50	6	54	77.0	1456.50	" "
69..	*F*	B. S.	*D*	77.75	5	55	75.5	1078.00	" "
70..	*F*	B. S.	*D*	79.50	5	55	77.25	978.5	" "
77..	*F*	B. S.	*E*	78.00	4	56	75.75	956.25	" "
78..	*F*	B. S.	*E*	78.25	4	56	75.75	935.25	" "
47..	*N*	B. S.	*A*	75.75	22	38	71.5	364.25	Crumbled.
48..	*N*	B. S.	*A*	79.75	22	38	75.25	414.5	"
55..	*N*	B. S.	*B*	77.25	18	42	72.25	267.0	"
56..	*N*	B. S.	*B*	77.00	18	42	70.5	560.0	"
63..	*N*	B. S.	*C*	77.75	9	51	72.75	596.0	"
64..	*N*	B. S.	*C*	77.25	9	51	72.25	422.5	"
71..	*N*	B. S.	*D*	75.0	8	52	71.0	203.0	"
72..	*N*	B. S.	*D*	77.0	8	52	72.0	318.75	"
79..	*N*	B. S.	*E*	77.25	4	56	73.5	486.0	"
80..	*N*	B. S.	*E*	77.75	4	56	73.0	419.5	"

NOTE.—An excess of variable quantity remained over after the making of each pair of bars.

TABLE No. 13.—ABSORPTION TESTS.

No. of bar.	Age, in days.	Weight of bar.	Condition before absorption.	WEIGHT, IN POUNDS, AFTER BEING SUBMERGED.	
				1 day.	2 days.
1.....	381	71	hard.	74.0	74.0
9.....	381	50	"	51.5	51.5
11.....	381	73	"	75.5	75.5
17.....	379	39	"	40.0	40.0
19.....	376	74	"	76.0	76.0
27.....	376	72	"	73.5	73.5
35.....	370	69	"	72.5	72.5
41.....	346	77	"	78.5	78.5
49.....	346	75.5	"	76.5	76.5
51.....	346	79.5	"	81.0	81.0
57.....	342	78.5	"	79.5	79.5
59.....	342	78.5	"	79.5	79.5
63.....	325	72	crumbling.	75.0	75.0
67.....	320	77.5	hard.	78.5	78 5

NOTE.—The temperature of the water in which bars were submerged was that of the water in St. Mary's River, about 50° Fahr.

The results, as observed from these tests, are summarized in Table No. 14 and Fig. 1, from which deductions can be drawn by those interested in investigations of the theory of concrete.

TABLE No. 14.—TABULATED RESULTS.

KIND OF CONCRETE.			Constant "C."	Absorption in per cent. of volume.	KIND OF CONCRETE.			Constant "C."	Absorption in per cent. of volume.
Cement.	Aggregate.	Mixture.			Cement.	Aggregate.	Mixture.		
E.....	S. S.	*A*	9.91	9.6	*E*.....	B. S.	*A*	18.16	4.8
E.....	S. S.	*B*	12.23	7.0	*E*.....	B. S.	*B*	18.44	3.2
E.....	S. S.	*C*	15.75	6.0	*E*.....	B. S.	*C*	20.93	3.2
E.....	S. S.	*D*	18.26	.....	*E*.....	B. S.	*D*	22.64	.....
E.....	S. S.	*E*	5.87	.....	*E*.....	B. S.	*E*	18.52	.....
R.....	S. S.	*A*	9.59	.....	*R*.....	B. S.	*A*	19.49	.....
R.....	S. S.	*B*	9.91	8.0	*R*.....	B. S.	*B*	20.80	4.8
R.....	S. S.	*C*	14.76	6.4	*R*.....	B. S.	*C*	21.98	3.2
R.....	S. S.	*D*	17.32	4.8	*R*.....	B. S.	*D*	22.05	3.2
R.....	S. S.	*E*	10.31	11.2	*R*.....	B. S.	*E*	18.09	.....
F.....	S. S.	*A*	4.12	.....	*F*.....	B. S.	*A*	8.12	.....
F.....	S. S.	*B*	6.57	.....	*F*.....	B. S.	*B*	9.78	.....
F.....	S. S.	*C*	8.96	.....	*F*.....	B. S.	*C*	9.30	.....
F.....	S. S.	*D*	6.79	.....	*F*.....	B. S	*D*	8.03	.....
F.....	S. S.	*E*	7.29	.....	*F*.....	B. S.	*E*	6.84	.....
N.....	S. S.	*A*	0.00	.....	*N*.....	B. S.	*A*	2.89	.....
N.....	S. S.	*B*	2.23	.....	*N*.....	B. S.	*B*	3.05	.....
N.....	S. S.	*C*	1.87	.....	*N*.....	B. S.	*C*	3.72	9.6
N.....	S. S.	*D*	2.37	.....	*N*.....	B. S.	*D*	2.00	.....
N.....	S. S.	*E*	1.96	.....	*N*.....	B. S.	*E*	3.33	.....

NOTE.—Constant "C" $= \dfrac{\text{Span in feet} \times \text{Load in pounds.}}{\text{Width in inches} \times \text{Depth in inches}^2}$.

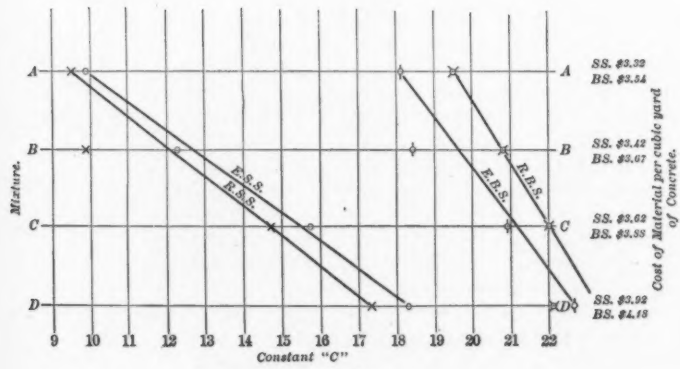

FIG. 1.

Mr. Fuller. WILLIAM B. FULLER, M. Am. Soc. C. E. (by letter).—There is one point which, it seems to the writer, has not been made sufficiently clear in this discussion, although it is really the basis of the most economical mixture for any given quantity of cement. If we make a concrete by using merely cement and sand, or cement and stone, it will take a large amount of cement to fill the voids in the sand, or in the stone, for any given quantity of concrete; but if we make a concrete of cement, sand and stone, the sand fills the larger voids in the stone and the cement has only to fill the remaining voids in the mass; a very much smaller percentage than in either of the first two cases. If, in the mixture of cement, sand and stone, the sand and stone are not in proper proportions, the cement is called upon to do more work than it should; that is, it has to fill the larger voids of this excess material. Take, for instance, sand having 45% voids, and stone having 40% voids. With the sand just filling the voids of the stone, it is easily calculated that the resultant mass has 18% voids; but supposing an excess of 10% of sand, there would be 10% of the material having 45% voids, which means there would be 2.5% more voids in the resultant mass.

The 2.5% of cement necessary to fill these extra voids, it is seen, is really wasted, for the resultant concrete would have been much stronger if the sand had been decreased and the stone increased, leaving the same amount of cement 2.5% in excess in the mass.

The above example indicates what frequently happens in mixing concrete. Indeed, it is what is frequently advocated in discussion and by writings on the subject; that is, to make up a mortar of cement and sand and mix this mortar with the stone, being sure that the mortar is slightly in excess, so as to fill all the voids of the stone.

This is what is known as drowning the stone, and the resultant concrete is hardly any better, so far as its properties are concerned, than a concrete of cement and sand alone. After the stone is once drowned no addition of mortar will improve the concrete.

The writer has frequently made a rich concrete of a poor one by simply rearranging the proportions of sand and stone without in the least changing the proportions of cement in the mass.

It must be apparent that there is just one proportion and only one in which any two such materials as sand and stone can be combined and give a minimum number of voids in the resultant mass, and it seems to the writer that this is the proportion in which they should always be mixed, whether we want a poor or a rich concrete. Mix the sand and the stone in a definite fixed quantity as determined by experiment for the particular material in use, and then add cement as economy dictates, possibly up to 10% in excess of the voids of the combined material.

This suggests another proposition, which must be almost self-evident, namely, that the proper selection and grading of the sand

and aggregate so as to produce the least number of voids will allow of a corresponding reduction in the amount of cement used, without reducing the quality of the concrete desired. In making up such mixtures, however, the necessary relation of the size of the particles of the different materials should be kept in mind, that is, the particles of each material should be small enough to enter easily the voids formed by the particles of the next larger material; otherwise, they will be left out and themselves form voids, which must be filled by the finer material or remain unfilled, to the detriment of the concrete. Mr. Fuller.

It is quite common to find sand used which is too fine for the cement, or sand in which the larger particles act merely as stone, or stone with its voids partly filled with sand or dust.

The proper proportions of sand and stone can be determined by mixing sample batches and determining their voids by any of the well-known methods; or, another very satisfactory method, as it also gives information as to the relative sizes of the materials, is to make a mechanical analysis of all the materials in the manner prescribed by the Massachusetts State Board of Health for the analysis of sands, and from the resultant curves figure the composition giving the highest uniformity coefficient. The writer has used the foregoing methods in concrete structures with uniform success in the reduction of the amount of cement required, without reducing the apparent quality, and, by changes in the proportions of the aggregates, has maintained a uniform quality of concrete, through the use of a wide range of aggregates, without changing the percentage of cement.

In discussing the relative merits of hand-mixed and machine-mixed concretes it is quite essential that the kind of machine with which the comparison is made should be stated, as there is as much difference between the products of different machines as between that of good and poor hand-mixing. With a machine of the cubical-box type, into which all the materials, including the water, can be measured accurately, the product, as far as observation can establish it, is superior to the best hand work. With such a machine the writer has seen concrete, of almost absolutely unvarying quality and consistency, produced for days at a time.

G. L. Christian, Assoc. M. Am. Soc. C. E. (by letter).—The writer has had considerable experience with hand-made concrete, but none with machine-made. Mr. Christian.

The hand-made concrete, to be of any use, requires continual, hard and conscientious work on the part of the mixers, and continual inspection by an intelligent, live and honest inspector, who will always insist on having everything done well.

The instant the inspector turns his back, the temptation to turn the water on the mortar, before the sand and cement are thoroughly mixed, and, in fact, before they are mixed at all, is too much for the

Mr. Christian.

average laborer to resist, especially if he is hard pushed and the day is hot. Taking all things into consideration, the writer would expect to find machine-made concrete superior to hand-made in a large majority of cases.

Only in cases where concrete is exposed to the sun does the writer agree with Mr. Gould as to the advisability of keeping concrete moist for a long time after being placed in the work. The writer has reached this conclusion, partly as a result of a test of quite a number of briquettes which were mixed about five years ago and recently broken. Some were of neat cement, some 2 to 1 and some 3 to 1. One set of each of these was mixed with fresh water, one with 3% salt water, and the other with 13% salt water. Half of each set of briquettes was laid away on wooden shelves in a warm office soon after mixing, and the other half was placed in water and kept there until ready to be broken. Many of these briquettes, have been broken, and, so far, those of whatever kind which were kept dry have shown the greatest tensile strength.

The writer was at one time a firm believer in the dry mixing of concrete. but having seen several thousand cubic yards mixed dry and placed to a depth of 6 ins. over a reservoir bottom, and afterward over 3 000 cu. yds. mixed wet, in the proportion 1: 3: 6, and placed in the other half of the same reservoir, he became a firm advocate of wet mixing.

A careful force account was kept on the last 3 000 cu. yds., in order to ascertain the actual cost per cubic yard. The wages paid were: Foremen, $2.50; laborers, $1.35; and teams, including driver, $4.00 per day. To the cost of each item in the force account 9% has been added for superintendent, timekeeper, office help, etc., and is included in the figures here given. The cost of blasting is not included, because the contractor was paid for excavating the rock, so that the cost begins with the loading and hauling to the crusher. The average haul was 400 ft. to and from the crusher.

The cost per cubic yard is subdivided as follows:

Sand	$0.40	
Natural cement	1.18	
		$1.58
Loading and hauling to crusher	$0.27	
At crusher	0.21	
Rent of "	0.01	
Coal at "	0.05	
Hauling from "	0.16	
		0.70
Concreting gang:		
Foremen	$0.05	
Laborers	0.54	
Teams	0.09	
		0.68
Total		$2.96

ALFRED F. HARLEY, M. Am. Soc. C. E. (by letter).—The "theory of concrete" is certainly a subject upon which civil engineers should be well informed, but, nevertheless, the fact remains that the execution is invariably left to a contractor, who, while carrying out the instructions of the civil engineer, is required to guarantee the success and perfection of the work. Mr. Harley.

On one occasion the writer was consulted by the proprietor of a livery stable who had taken from a local contractor a sub-contract for hauling cement, sand and broken stone by the cubic yard, and, upon presenting the bill, was informed by the contractor that inasmuch as the concrete had required 1 part of cement, 3 parts of sand and 6 parts of broken stone, making a total of 10 parts, while the actual number of square yards of concrete laid, 6 ins. thick, was approximately 60 000 sq. yds., or about 10 000 cu. yds. of concrete, and consequently the stable proprietor could only have hauled 1 000 cu. yds. of cement, 3 000 cu. yds. of sand and 6 000 cu. yds. of broken stone. All of which argument the livery stable proprietor followed very clearly in mind, but failed to check with the actual number of loads the teams had carried, even when taking into consideration the assumption that a quantity of the material might have been dropped along the road. The writer was not made a party to the settlement finally reached, but the shrinkage of the material when rammed was certainly not taken into consideration.

The writer cannot agree with Mr. Tillson as to the economic use of a machine-mixer for street concrete work. The figures Mr. Tillson gives should at least be reversed, 7 cents being, in the writer's estimation, a minimum figure for hand-made concrete and 10 cents a minimum figure for machine-mixed concrete. Neither is the result equally good, in the writer's opinion. The wheeling for any distance in a barrow tends to bring the mortar to the bottom, while the most valuable part of the concrete, commonly called "the slush," is wasted along the run-boards and could not be picked up and used before the initial set had taken place; while the amount of water cannot be regulated as nicely in the closed trough of the machine as when allowed to run on the concrete from a hose as it is turned over by hand.

Where continuous shoveling has to be performed, as with concrete mixed by hand, it is infinitely less fatiguing to the laborer if a steel plate is used to shovel on instead of boards. Gravel is also much more easily shoveled than broken stone.

Mr. Dunham's remarks in regard to the use of broken stone and the dust obtained in breaking are interesting. In gravel deposits there is found frequently a good quality of sand in such proportion as to fill entirely the voids between the gravel. A great many civil engineers require the material to be screened, and the sand and gravel

Mr. Harley. used separately in the proportion specified. Lately, this class of material has been used by a Government official without screening, and with very good result; and it is only reasonable to suppose that at the time the gravel deposit was formed, the voids were filled entirely with the fine particles of sand washed into as close a position as they could very well occupy.

The advantage in hand-mixed concrete, in the writer's estimation, is not only in cost, but in the rapidity with which the concrete is put into position after being mixed, and the proximity of all the materials to their final resting place. One practice which the writer very firmly believes in following, is to throw a few shovels full of mortar, when mixed on the board, over the top of the last batch of concrete just previously laid, and by this means fill the interstices flush with the surface of the concrete. It might be claimed that a batch would then contain less mortar than it should, but this is not so, inasmuch as the operation is repeated over each batch thrown into position.

In New Orleans, during the execution of some contracts, the writer had an opportunity to run a hand-concrete gang at the same time that another firm of contractors was operating a concrete-mixer gang, and not only in the employment of less men, but also in the number of square yards laid during the day, were the results of the two methods under discussion apparent, and decidedly in favor of the hand-mixed concrete.

A day's work, in running three boards extending the full width of the street, would average about 900 sq. yds. of concrete 6 ins. thick, which result is all that could be wished, from the following gang:

6 wheel-barrow men—broken stone or gravel.
3 " " " —sand.
1 " " man—cement.
2 men opening cement.
7 " dry mixing.
8 " taking off boards.
3 " tamping concrete.
3 " grading concrete.
1 man attending to run planks.
3 water boys.
1 or 2 extra men, or, in all, say, 40 men.

The writer believes that Mr. Hall will find it quite customary in Europe to use broken stone, gravel, sand and cement in concrete, in certain quantities.

Mr. Rafter. GEORGE W. RAFTER, M. Am. Soc. C. E. (by letter).—The author desires to express satisfaction at the appreciative discussion of the paper. That there is an important place in the literature of concrete for a paper of this character is well indicated by the remark of Mr. Fowler:

Mr. Rafter.

"Many writers on this subject have assumed that every concrete, no matter what the proportions may be, has simply a yard of broken stone, without regard to the fact that there is more or less mortar in different proportions."

The author has been greatly surprised, in looking over the literature of concrete, to see how far this fallacy has been accepted. It has also been matter of surprise to find a nearly absolute dearth of definite information as to the amount of mortar and concrete produced by definite proportions of cement, sand and broken stone, as well as the unit weight of the resultant concrete.

This paper, taken in connection with the more extended information given in the report to the State Engineer and Surveyor of New York, is an attempt to supply, in some slight degree, what appears, after study of the question, to be a very material deficiency. The results are, however, unsatisfactory to the author in this particular; that, having laid out the plan of work, no special study of the data was made until about two years after the completion of the tests. This was a mistake. The data should have been tabulated and studied from day to day during the progress of the tests. Had this been done, there seems to be no doubt that some of the irregularities of the results could have been eliminated.

The subject is extremely complicated, many apparently insignificant elements entering in to detract from the strict, scientific accuracy of the results. The more especially is this true, as in the present case, where an attempt has been made to keep the results on practical lines purely, using only such methods as could be applied in practice on work, without adding unduly to the cost of concrete. However, taking this latter condition into account, the author reiterates the view expressed in the paper, that the results are very good.

Occasion is taken at this place to especially call to the attention of those participating in the discussion, that the results of these tests are given in great detail in the annual report of the State Engineer and Surveyor of New York for 1897.* The results of a previous set of tests made in 1893 are given in the annual report of the State Engineer for 1894. Reference to all these reports should be made by anyone wishing full data.

As regards mixing concrete, either by hand or machinery, the author's experience is that with proper supervision, good concrete can be obtained by either method. As remarked by Mr. Tillson, the difficulty in hand mixing is to insure thorough work. On this point the author has found that by drilling a gang of laborers to work strictly according to formula, performing each operation in the same way, every time, there is little difficulty about securing fairly uniform results by hand mixing. Nevertheless, the author's opinion is that

*See also "Report on Tests of Metals and other Materials," Watertown Arsenal, for 1898, where may be found, also, results of other concrete tests.

Mr. Rafter. proper machine mixing is preferable, as leading to a uniformity of product which, while possible to attain by hand mixing, is still somewhat difficult. In a general way, the author agrees, therefore, with the statement of Mr. Gould, that no hand-made concrete, using the same proportions, can equal a machine-made product, because of the thorough way in which the machine churns up the entire mass.

The tests show that dry concrete is considerably stronger than that made with excess of water. As stated in the report to the State Engineer and Surveyor, the author's experience has taught him that the only way in which dry concrete can be safely used, especially in warm weather, is to wet the surface thoroughly as soon as the ramming has been completed, and to keep the surface wet until after the completion of the setting. This procedure will be likely to prevent the formation of the partings between successive beds referred to by Mr. Gould. The author, however, does not intend to be insistent as to the use of dry concrete, but rather presents the results of these tests for comment and professional criticism. He is, nevertheless, well satisfied that dry concrete, with the mortar comprising 40% of the aggregate material, can be made practically water-tight. In recent work with a concrete of this composition, a dam has been constructed, which, with one exception, shows absolutely no moisture on the face. The one exception is two pin holes, both within an area of 1 sq. ft. Their presence can only be taken to indicate careless work—for the moment, evidently, vigilance was relaxed—but this single exception can hardly be taken as proving the inapplicability of dry concrete. In any case, it is certain that plastic and excess concretes can be used much more easily than dry, and the practical question is, after all, whether the gain in strength is enough to compensate for the increased chance of poor work.

As to ultimate strength, it seems certain that time is a great eliminator of the differences between dry, plastic and excess concretes, the tendency being, undoubtedly, to show less and less difference in ultimate strength with increase of age.

The concrete blocks here discussed were made between July 10th and September 5th, 1896. They were broken between January 29th and May 10th, 1898. The ages of the blocks, therefore, varied from about 670 to about 570 days. The exact age of each block may be obtained by reference to Table No. 1 of the report to the State Engineer and Surveyor, in the annual report for 1897.

One important point which the author had in mind in making these tests was to show that, for many purposes, the formulas in common use give concretes which are unnecessarily expensive. Thus, for foundations which are entirely under water there is no object, so far as the author can see, in spending the money necessary to make an absolutely impervious concrete. For such work a 30 or 33%

concrete is apparently sufficient. The same is also true of retaining walls, for which concrete is now used extensively, and through which weep holes can be left, thus insuring that water will not penetrate any considerable distance into a 30% concrete, and which may, as the author is well aware, contain a slight percentage of voids. Mr. Rafter.

Where water-tight work is required, the mortar may be made from 40 to 45% of the aggregate. By using different sized stone for the aggregate, there seems to be no doubt that 40 to 42% of mortar will make a practically water-tight material. The author says practically water-tight, because the quality of the mortar will, in some degree, decide as to absolute water-tightness.

In the original tests of 1893, the ratio of broken stone to mortar was made mostly 42%, a few blocks having been fabricated with the ratio of 30 per cent. These blocks were all broken under the author's personal supervision, and none of the 42% blocks exhibited any voids visible to the eye. They were, in the best sense of the word, solid blocks. Blocks of 30 and 33%, however, exhibit some voids, the greatest difficulty with such concretes being to make them absolutely fill out all the voids next to the forms. This is a difficulty which is, however, very easily corrected by using a somewhat larger proportion of mortar next to the forms, as has frequently been done with good success on work.

In the series of tests made in 1896, and which are here specially considered, the author is unable to say as to whether there were any appreciable voids in the 33% concretes, but from his experience with the 30% concretes made in 1893, he would be disposed to say that the voids were very small, especially in the plastic and excess concretes. Under this head it may be pointed out that the effect of ramming is to decrease the voids. This was strongly brought out by a series of tests in which it was found that the Portage stone, broken to pass through a 2-in. ring, when slightly shaken in the measure, gave, as a mean of five trials, 43.3% voids. The same stone packed in a measure with a tamping iron, used about as forcibly as the ordinary ramming of concrete, gave, as a mean of five trials, 37.4% voids. In these tests the air was driven out of the voids entirely.

The author has little doubt that, with the lubrication of the mortar, the voids are reduced, under thorough ramming, to not much more than about 30 per cent. It is from this point of view that he decided to use 33% of mortar in the tests herein discussed, that quantity of mortar being enough to just about insure filling the interspaces of the stone. Such a concrete will not, however, be absolutely water-tight.

In the same way the excess of mortar in 40% concrete was considered to be large enough to insure practical water-tightness. It is possible, however, that slightly larger proportions than the foregoing should, in some cases, be used. On the other hand, by selecting aggregate ma-

Mr. Rafter. terials of different sizes, thus reducing the proportion of voids, it is believed that the proportions of 33 and 40% fairly meet the great majority of cases.

Mr. Conrow points out that the average ratios of strength are, for concretes with dry mortars, 29.1; plastic, 26.6; excess, 25.3; as based on the average of ten tests. From these figures he deduces that dry concrete is about 15% stronger than wet. In his experiments as to relative cost of laying wet concrete *versus* dry concrete, he found that wet concrete could be fabricated at a cost for labor of $1.13 a yard, dry concrete costing, with other conditions the same, $2.12 a yard. This is for hand labor. The author's experience is that for machine-mixed concrete, aside from ramming, the cost will be no greater for dry than for wet. As an average, the ramming of dry concrete will cost 25 cents per yard more than for wet.

Mr. Hazen's discussion of the conditions involved in the determination of voids, and as to the weight of concrete, illustrates forcibly how far we are from appreciating the practical considerations to be taken into account in making concrete, especially when the subject is approached from the theoretical point of view purely. However, as to determining the voids, the use of the method outlined by Mr. Hazen seems to the author to give results too large. Independent of its lack of applicability out on work, the author believes that the displacement method of determining voids is, for clean material, much the better. A knowledge as to the interstices in the aggregate material or ballast is wanted, and not, in any degree, the porosity of the material. The author does not wish to be understood, however, as saying that information as to the porosity of aggregate material may not be of importance, the more especially since such information is very necessary in order to decide between different samples. His point is, that, as regards concrete mixtures, what is wanted is the volume of the interspaces between the stones, independent of the porosity. Limestones, sandstones and other aggregates are often quite porous, and the method by specific gravities apparently takes into account this porosity. Limestones sometimes absorb 5% of their weight of water, and sandstones as much as 7%, while broken brick may absorb 20 per cent. As fair averages, we may take limestone at 3%, sandstone 4%, and broken brick 10 per cent. The most practical way to proceed is to first thoroughly wet the broken stone and allow it to drain before placing it in the measure. Water should then be poured in slowly and at one corner of the measure, thereby insuring the driving out of the air. For sand, absorption into the pores is so small that it may be neglected, but it is important to pour in the water slowly and at one corner of the measuring box. This procedure applies to clean sand. For sand containing much vegetable mould or other foreign matter, Mr. Hazen's remarks as to the uncertainty of the displacement method apply

forcibly. As regards the penetration of water into the pores of the aggregate material, it may be remembered that the smearing of the broken stone with mortar tends to seal up the pores in properly-made concrete, thus preventing the ingress of any considerable amount of water. In any case, taking into account the porosity of the aggregate material is a misleading refinement. Mr. Rafter.

There is no reason why, with care, any ordinarily intelligent foreman cannot, by the foregoing simple method, determine quickly the voids in aggregate material and clean sand, as often as required, and well within any limit of accuracy needed for proportioning concrete.

Reference has already been made to the original series of tests of 1893, and which are reported upon in the annual report of the State Engineer and Surveyor for 1894. The weights of the 42% blocks fabricated at that time ranged from about 145 lbs. per cubic foot to about 150 lbs., the variation in weight being in some proportion to the strength of the mortar, blocks with 1 to 1 mortar being heavier than those with 1 to 2 or 1 to 3. In some cases, cubes of 1 ft., with 1 to 1 mortar, 42%, weighed from 150 to 160 lbs. The tests of the series of 1893 are, however, unsatisfactory in this, that the exact dimensions of the blocks were not taken, and there is probably some uncertainty in the figures on this account.

In the tests of the series of 1896, and which are here specially considered, no such uncertainty exists; the exact dimensions of each block were taken carefully, and the weights per cubic foot computed therefrom. In Table No. 15 we have the mean weights of all the concrete blocks in pounds. The Portage sandstone used as ballast weighs 155 lbs. per cubic foot, and has, when crushed in 12-in. cubes, a crushing strength of 6 000 to 7 000 lbs. per square inch. A few determinations of weight of mortar used show the following mean weights per cubic foot:

			Weight per cubic foot.
Empire	cement—	1 to 2 dry.....	126.4 lbs.
"	"	1 " 3 "	120.9 "
"	"	1 " 4 "	119.1 "
"	"	1 " 2 plastic.....	124.7 "
"	"	1 " 3 "	121.0 "
"	"	1 " 4 "	119.2 "
Iron Clad	"	1 " 2 dry.....	128.5 "
"	"	1 " 3 "	124.8 "
"	"	1 " 4 "	120.9 "
Champion	"	1 " 1 "	126.2 "
"	"	1 " 2 "	123.8 "
"	"	1 " 3 "	119.2 "

The foregoing weights of mortar blocks, as well as concretes, included in Table No. 15, are all as taken at the time of breaking, and

Mr. Rafter. when, presumably, the excess water had evaporated. This conclusion is reached by considering that the blocks stood in a dry, warm place for some time before breaking.

Referring to Table No. 15, it appears that there was very little difference between the weights of 33 and 40% blocks. With the Genesee cement 1 to 1 mortars, the mean weights are, for 33% blocks, 146.5, and for 40% blocks, 145.6. For Wayland, 1 to 1 mortars, the mean figures are 33%, 146.9; and 40%, 145.8. For Genesee 1 to 2, the figures are, 143.8 and 143.7; and for Wayland 1 to 2, 144.5 and 144.2.

For the Genesee cement, the weight per cubic foot was taken at 99.5 lbs.; for the Wayland, 100 lbs.; for the Iron Clad, 97 lbs.; for the Empire, 99.5 lbs., and for the Champion, 87 lbs. The reason that the weights of 33 and 40% blocks are practically the same is probably because in 33% blocks the excess reduction of voids under ramming just about compensates for the extra quantity of mortar in the 40% blocks, the relation between the weights of mortar and broken stone being such as to give this result. The persistency of the figures through the whole series shows that this result is not accidental, but rather the expression of a well-defined law.

TABLE No. 15.—Mean Weights of Concrete Blocks.

(In pounds.)

		1 to 1.		1 to 2.		1 to 3.		1 to 4.		1 to 5.		1 to 6.	
		33%	40%	33%	40%	33%	40%	33%	40%	33%	40%	33%	40%
Genesee.	Dry	146.6	.....	.....	143.4	142.7	142.9	141.3	141.6	140.5	.....	139.5	.....
	Plastic	146.2	.....	143.2	143.4	143.2	142.4	142.1	140.7	141.2	.....	.....	.....
	Excess	146.6	145.6	144.5	144.4	142.9	141.9	143.1	141.2	.....	.....	.....	.....
	Mean	146.5	145.6	143.8	143.7	142.9	142.4	142.2	141.2	140.8	.....	139.5	.....
Wayland.	Dry	147.0	146.4	144.5	144.4	140.0	142.1	142.6	140.0	141.7	139.7	.....	.....
	Plastic	147.8	146.4	145.1	143.5	144.1	141.0	141.2	141.6	140.8	139.0	.....	.....
	Excess	145.9	144.7	144.0	144.6	140.7	141.6	141.3	142.2	139.8	140.4	.....	.....
	Mean	146.9	145.8	144.5	144.2	141.6	141.6	141.7	141.3	140.8	139.7	.....	.....
Iron Clad.	Dry	.....	.....	143.7	144.2	141.5	141.6	141.7	140.6	.....	.....	.....	.....
	Plastic	.....	.....	143.0	143.6	141.0	141.1	140.4	140.6	.....	.....	.....	.....
	Excess	.....	.....	143.3	144.2	140.9	141.8	141.9	140.2	.....	.....	.....	.....
	Mean	.....	.....	143.3	144.0	141.1	141.5	141.3	140.5	.....	.....	.....	.....
Empire.	Dry	.....	.....	142.6	144.3	140.5	140.8	139.8	139.7	.....	.....	.....	.....
	Plastic	.....	.....	142.9	144.0	141.5	141.1	141.4	140.4	.....	.....	.....	.....
	Excess	.....	.....	144.6	143.7	141.7	141.7	141.1	139.4	.....	.....	.....	.....
	Mean	.....	.....	143.4	144.0	141.2	141.2	140.8	139.8	.....	.....	.....	.....
Champion.	Dry	142.5	143.1	142.7	140.3	138.9	139.4	.....	.....	.....	.....	.....	.....
	Plastic	142.4	142.8	142.3	141.3	140.6	138.3	.....	.....	.....	.....	.....	.....
	Excess	141.5	142.2	140.5	142.7	139.4	139.0	.....	.....	.....	.....	.....	.....
	Mean	142.1	142.7	141.8	141.4	139.6	138.9	.....	.....	.....	.....	.....	.....

While many of the points brought out by the discussion are of great practical interest, the author wishes to say that many more interesting points could have been touched upon; as, for instance, the

change of volume of mortar material when water is added, the effect of ramming on consolidation of mortar itself, the consolidation or reduction of void space in the aggregate material under ramming, the probable greater reduction of such space with rich mortars which act more thoroughly as lubricants, and many others which could be mentioned. The paper itself was purposely left a bare recital of main facts in regard to the tests, of which the detail is given in the report to the State Engineer and Surveyor, the author's hope being that all the various points of view would be taken up in the discussion. That many of them are left untouched, seems to show, on the whole, a lack of appreciation of the theory of concrete; at the same time the author agrees thoroughly with Mr. Hall that there is no reason why the old nomenclature should obscure, from those who are looking for it, the true theory of concrete mixtures. Nevertheless, the fact remains that apparently either that or some other cause has so far obscured the true theory of concrete mixtures that American engineering literature is, in the last year of the nineteenth century, practically barren of rational information as to the theory of concrete. Mr. Rafter.

Professor Baker's view, that 40% concretes should show an excess of strength over 33% concretes in the same proportion to the excess percentage of mortar, is not supported by the results of these tests. The reason probably is that in 33% concretes the strength is largely dependent upon the close bearing of the broken stone, while in the 40% concretes it is, in a somewhat larger degree, dependent upon the strength of the mortar. Professor Baker, however, is right in his conclusion that, as regards final results, the method of storage is not very important for concrete which has, as in the present case, attained an age of at least a year and a half. Had the blocks been broken at an earlier period, they would probably have shown greater differences than those indicated by Table No. 7.

As to the variation in the strength of the concrete, under the same conditions for the different cements, the author has no explanation to offer, other than that it is possibly due to varying qualities in the cements themselves which have not thus far been closely differentiated by the methods of tests actually in use.

Mr. Le Conte has indicated the true phase of concrete practice at the present time by his remark that "it is a humiliating spectacle to see first-class material, manipulated in an irrational and wasteful manner, developing results which cannot be shown to possess a single redeeming feature." Especially is this true as regards the cleanness of the aggregate material. The broken stone should, in every case, be washed clean, and indeed cleanness should be made an indispensable condition at every stage of the operation. That such conditions are not generally insisted upon, merely illustrates how far many of us are from understanding the true theory of concrete. These remarks

Mr. Rafter. apply to a considerable proportion of the concrete used at the present time in the United States.

The tests recorded by Mr. Von Schon are very interesting, especially as to the general programme which he outlines. His first condition, to operate practically, avoiding the introduction of refinements which cannot be followed in actual construction, is thoroughly in line with the author's views, as is also the second. The author cannot but think, however, that Mr. Von Schon's tests would have been more satisfactory had they been on the line of crushing rather than breaking bars by applying a load at the center, though it is recognized that this is, after all, merely a difference of opinion; the author's contention being, however, that had Mr. Von Schon broken a number of cubes, the results would have been comparable with most of the results thus far obtained, whereas, as the matter stands, it is impossible to compare them.

By way of showing the variations in the quantity of green mortar produced from the same quantity of cement and sand, but with such variation in the quantity of water as is necessary to produce dry, plastic or excess mortars, the following figures are cited:

For 1 to 3 mortars, $\frac{2}{3}$ cu. ft. of cement and 2 cu. ft. of sand produced quantities of mortar in cubic feet, as follows:

	Genesee.	Wayland.	Iron Clad.	Empire.	Champion.	Means.
Dry.....	2.05	2.12	2.19	2.16	2.13	2.13
Plastic...	2.21	2.16	2.23	2.25	2.18	2.21
Excess...	2.25	2.16	2.28	2.29	2.15	2.23

For 1 to 2 mortars, 1 cu. ft. of cement and 2 cu. ft. of sand, produced quantities of mortar in cubic feet, as follows:

	Genesee.	Wayland.	Iron Clad.	Empire.	Champion.	Means.
Dry.....	2.51	2.37	2.57	2.50	2.22	2.43
Plastic...	2.58	2.49	2.62	2.58	2.43	2.54
Excess...	2.75*	2.58*	2.62*	2.61	2.48	2.61

Inasmuch as the cement was weighed, thus insuring the same quantity in each series, the irregularities in these results are chargeable to variations in sand and quantity of water.

The author wishes to thank those who have taken part in the discussion for the many valuable suggestions made. In view of the large number of works, now either in progress or contemplated, in which concrete is either in use or to be used, the author hopes that the general question of the rational relation between the voids in the aggregate material and the amount of mortar, especially in relation to unit costs, and other important questions, may be so thoroughly taken up as to lead to final, definite conclusions. The present paper was intended to be largely suggestive.

* One determination only.